XVI INTERNATIONAL GEOLOGICAL CONGRESS

GUIDEBOOK 16 - - - - EXCURSION C-1

MIDDLE CALIFORNIA AND WESTERN NEVADA

International Geological Congress
XVI session
United States, 1933

Guidebook 16: Excursion C-1

MIDDLE CALIFORNIA AND WESTERN NEVADA

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UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON : 1933

For sale by the Superintendent of Documents, Washington, D. C. - - - Price 20 cents

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This guidebook is published under the auspices of the United States Geological Survey, but it is not a part of the Geological Survey's regular series of publications, and the opinions expressed in it and the use of nomenclature do not necessarily conform to Geological Survey usage.

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From Mining in California, January, 1931. Photograph used by permission of H. A. Sedelmeyer. Dotted lines show routes of excursions. 1, Klamath Mountains; 2, Columbia-Cascade province (2a, Cascade Range; 2b, Modoc Plateau); 3, Sierra Nevada; 4, Great Valley; 5, California Coast Ranges; 6, Basin and Range province (6a, Great Basin; 6b, Mohave Desert; 6c, Salton Trough;) 7, Lower California province. Boundaries of geomorphic provinces supplied by N. E. A. Hinds; faults by J. P. Buwalda.

MIDDLE CALIFORNIA AND WESTERN NEVADA

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THE GEOLOGY OF MIDDLE CALIFORNIA

By Andrew C. Lawson

GEOMORPHOLOGY

COAST RANGES

The dominant fact in the geomorphology of middle California (see pl. 1) is best expressed in a profile transverse to the elongation of the State. Such a profile shows two notable mountain ranges inclosing a great valley, the floor of which is nearly at sea level. The Coast Ranges, bordering the west edge of the continent, have a width of 70 miles (113 kilometers) and rise boldly from the Pacific Ocean. The eastern flank of the range that overlooks the valley is also an abrupt slope. The boldness of this slope has, however, been modified by atmospheric degradation; whereas the seaward flank is continually sharpened by the corrasion of the waves at its base. The higher ridges of the Coast Ranges are from 3,000 feet (914 meters) to over 4,000 feet (1,219 meters) high. Separating these mountain ridges are pronounced longitudinal valleys, the trend of which is determined by faults rather than by folds. The drainage pattern conditioned by these faults is subsequent in the sense that the long streams are parallel to the range.

Certain faults have been recently active, notably the San Andreas fault (pl. 2, *A*, *B*), on which a horizontal displacement occurred in 1906. Actual movement was observed and measured at numerous localities from Point Arena to San Juan Bautista, a distance of 187 miles (301 kilometers), and the maximum relative displacement, at Tomales Bay, was 21 feet (6.4 meters). The trace of the San Andreas fault, however, is several times longer than the portion on which movement occurred in 1906. It extends from the vicinity of Cape Mendocino to the Colorado Desert and probably beyond into the Gulf of California. Perhaps its most interesting structural feature is its course obliquely across the entire width of the Coast Ranges.

Off the coast is the continental shelf, which slopes gently seaward for about 50 miles (80 kilometers) from the shore and then descends more abruptly to a depth of about 12,000 feet (3,658 meters). At Monterey Bay there is a large indentation of the coast line, a low pass through the outer half of the Coast Ranges, and a profound submarine valley transecting the continental shelf. At San Francisco a depression of the Coast Ranges affords drainage at sea level for the great interior valley, including, of course, that from the mountains on each side. The coastal slope is scored by wave-cut terraces, some of which reach altitudes of more than 1,200 feet (366 meters). The stream terraces of the valleys are usually lower and less pronounced than the wave-cut terraces. It is probable, from the variation of altitudes of the terraces, that the seaward side of the Coast Ranges has been uplifted more than that which flanks the interior valley—in other words, that the Coast Ranges have suffered tilting.

The main structural features of the Coast Ranges, including faults, thrusts, and axes of folding, have a trend oblique to the general trend of the mountain belt. A line N. 27° W. from Santa Barbara to Eureka represents very closely the general trend of the Coast Ranges. The individual structural ridges and valleys are oblique to this general trend and consequently end abruptly at the coast line and at the valley border. They are related to the mountain belt, as regards orientation, like the tensional gashes to a shear zone.

In a geomorphic sense the Coast Ranges may be said to have attained the stage of maturity, but this statement requires some qualification. In the vicinity of the coast the canyons, in the zone of uplift indicated by the marine terraces, are, by renewal of the cycle, in early youth. In some parts of the ranges, where rocks exceptionally resistant to erosion prevail, the profiles are far from mature. In many places in the wider valleys the topographic expression is that of old age.

SIERRA NEVADA

On the northeast side of the Great Valley is the Sierra Nevada, symmetrical in position with the Coast Ranges on the southwest side but differing greatly from them in its geomorphic features. It is the westernmost, the largest, the simplest, and the best defined of the Basin Ranges. Its western slope is a stream-dissected tilted surface; its eastern slope is a degraded fault-line scarp. The intersection of the fault-line scarp and the tilted surface forms the crest of the range. The western slope is inclined at an angle of less than 2°. In part it passes

A. FURROW NORTHWEST OF OLEMA, MADE BY THE MOVEMENT THAT CAUSED THE EARTHQUAKE OF 1906

Photograph by G. K. Gilbert. From U. S. Geol. Survey Bull. 324, pl. 3, *A.*

B. VIEW LOOKING SOUTH ACROSS CARRIZO PLAIN, SHOWING SAN ANDREAS FAULT

Photograph copyright by Erickson, San Diego.

beneath the Tertiary and Quaternary deposits of the Great Valley, and in part it is dislocated from the valley floor by faults which still have pronounced geomorphic expression. The major drainage of the slope is consequent, the streams flowing in general directly down the slope. Only the Kern River, in the southern part of the range, deviates from this plan, flowing for many miles due south, nearly parallel to the crest line, in a straight canyon determined by a rift.

All the main rivers have intrenched themselves in deep canyons of youthful aspect, but many of their lesser tributaries still occupy shallow and mature valleys at a level considerably above the main canyons. These high valleys are believed to indicate a considerable interval of rest in the general uptilting of the range.

The upper part of the range, known as the High Sierra, owes much of its geomorphic expression to glacial sculpture. There are innumerable cirques, and the intersection of cirque walls has in many places been effective for the rapid reduction of mountain crests. The ice discharging from convergent cirques flowed down many of the large canyons for long distances. The terminal moraines of these valley glaciers are small, but their lateral moraines, at the sides of the canyons, are very large, constituting notable features of the relief even in the rugged mountains. Most of the high cirques now hold only tarns, but a few glaciers still remain.

The precipitous eastern slope of the Sierra Nevada is modified in the north by the steps of a broad fault zone. To the south the zone becomes narrower and is characterized by grabenlike basins, of which the most notable examples are Lake Tahoe (tah′hoe), Mono Lake, and Owens Valley. Along the mountain front there are blocks that form narrow, local steps owing to the fact that they were not downthrown as much as the country to the east. The finest examples of these are to be seen in the vicinity of Mono Lake.

GREAT VALLEY

The Great Valley of California is a structural depression between two mountain ranges. It is part of a system of longitudinal structural valleys extending along the Pacific coast, including to the south the Colorado Desert, the Gulf of California, and the depression between the Plateau of Mexico and the Sierra Madre del Sur, and to the north the Willamette (wil-lam′et) Valley, Puget Sound, the Gulf of Georgia, and Queen Charlotte Sound. The geologic significance of this system of valleys is not yet known.

The surface of the Great Valley is one of alluviation, sloping from sea level at its middle part to 309 feet (94 meters) at Red Bluff, on the north, and to 414 feet (126 meters) at Bakersfield, on the south, a slope both ways of about 1.5 feet to the mile (0.28 meter to the kilometer). The alluvial deposits come chiefly from the rivers of the Sierra Nevada, the largest of which have built out alluvial fans that extend to the Coast Ranges and form the dams of interior basins. The depth of the alluvial fill is not known, but it probably attains its maximum in the region of its outlet to San Francisco Bay, where the depression is greatest. At Stockton wells more than 3,000 feet (914 meters) deep penetrate fluviatile or lacustral deposits without reaching bedrock. Between Stockton and Marysville Buttes there are extensive swamp and overflow lands whose surface is very close to sea level. This condition appears to be significant of subsidence now in progress pari passu with the deposition of alluvium, for there seem to be no marine deposits in the valley fill. The terraces at Benicia and on the shores of San Pablo Bay indicate, however, that the outlet of the Great Valley has recently been uplifted about 20 feet (6 meters).

GEOLOGY

COAST RANGES

The oldest rocks of the Coast Ranges are certain quartzites, limestones, and crystalline schists that are extensively exposed in the Santa Lucia, Gabilan, and Santa Cruz Ranges. The age of these formations is unknown, except that they are pre-Cretaceous. These metamorphic rocks have been greatly disturbed and invaded by large intrusive masses of granite. The age of the granite is no better known than that of the formations which it intruded; but at the south end of San Joaquin Valley the granite appears to be the same as that of the Sierra Nevada and continuous with it, and thus, like that rock, it may belong to the end of the Jurassic period or the beginning of the Cretaceous. The granite is exposed in about a score of discrete areas extending through the Coast Ranges from Ventura County (Mount Pinos) to Sonoma County (Bodega Head), a distance of 325 miles (523 kilometers). It emerges in these places from beneath younger formations.

The rocks next in age to the granite are comprised in the Franciscan group. This is an extraordinary assemblage of continental and marine strata and volcanic rocks, which extends from Santa Catalina Island, south of Los Angeles, through the coastal region of California, Oregon, and Washington to the Olympic Mountains. The contact of the Franciscan formations with the granite has nowhere been observed except along faults,

but the failure to find granite cutting the Franciscan, the contrast of the Franciscan with the pregranite formations in original lithology and in kind and degree of metamorphism, and the arkosic character of the Franciscan sandstones are grounds for the belief that the basal rocks of the group rest upon the eroded surface of the granite.

The stratigraphy of the Franciscan group is best known in the San Francisco and Marin Peninsulas, where a sedimentary sequence of seven subdivisions has been made out, comprising four sandstones alternating with one limestone and two formations of radiolarian chert. The thickness of the group in this region is about 6,400 feet (1,950 meters). As the sandstones show prevailingly little or no stratification, the attitude of the beds is difficult to determine. This massive facies is a greenish-gray arkose with abundant flakes of carbonaceous material and a few large angular bodies of dark shale. Where the bedding is more apparent, owing to an alternation of sandstones and shales, lignitic layers occur. Lenticular layers of conglomerate or pebbly sandstone are present locally. The sandstone is prevailingly a continental formation.

The sedimentary record of Franciscan time is one of oscillation of the strand line. As the deltaic embankment broadened, the strand moved west; by submergence the strand moved east. The record conforms to the mobility which is so characteristic of the Coast Range province.

The age of the Franciscan group is still undetermined. It is usually designated as Jurassic (?), but if the Franciscan rests upon the eroded surface of the granite and if the granite at the south end of San Joaquin Valley is the same as the granite of the Sierra Nevada, as it appears to be, then the Franciscan must be post-Jurassic. Much field work must be done before this question can be settled.

Besides the sedimentary strata, the Franciscan group includes certain extrusive igneous rocks, and it is cut by intrusive rocks. Basaltic lavas are in some sections intercalated with sedimentary formations, and there are numerous intrusions of ellipsoidal basalt and peridotite, the latter now thoroughly serpentinized. The sedimentary rocks in the immediate vicinity of these intrusions are in general highly metamorphosed and give rise to zones of glaucophane and other crystalline schists.

The Cretaceous rocks of the Coast Ranges include the Shasta (Lower Cretaceous) group and the Chico (Upper Cretaceous) group, each of which contains several subdivisions. The maximum thickness of the series is 29,000 feet (8,839 meters).

The basal formation (Knoxville) rests in many places unconformably upon the worn surface of the Franciscan; but the

deformation of the Franciscan, though general, appears nowhere to have been acute, except in the incompetent formations like the radiolarian cherts. The pre-Knoxville erosion of the Franciscan rocks did not completely remove them in any of the sections that include the Knoxville, and in the Coast Ranges the Knoxville rests on no older rocks. Either the erosional interval was short, or, more probably, the Franciscan was nowhere wholly lifted above base-level.

The Knoxville formation consists prevailingly of shales, sandy shales, thin-bedded sandstones, and thin fossiliferous limestones. A basal conglomerate with small pebbles is of only local occurrence. The failure of the transgressing Knoxville sea to develop a persistent or coarse conglomerate indicates that the subsiding coast had been peneplaned, that there were no torrential streams discharging into the Knoxville sea, and that a broad transgression was effected by slight subsidence.

At the end of Lower Cretaceous (Shasta) time the landward border of the Knoxville basin suffered a sharp uplift while the basin itself continued to subside. From the uplifted region torrential streams built out into the basin extensive deltas of pebbles, cobbles, and boulders that constitute the Oakland conglomerate, which marks the end of Shasta sedimentation and the initiation of the Upper Cretaceous (Chico). Although significant of an acute uplift, the Oakland conglomerate does not repose discordantly upon the underlying Shasta formation.

The basin of deposition persisted through Chico time, expanding slowly, so that its deposits transgressed the limits of the Shasta formations. Over the greater part of the basin the Chico formation above the Oakland conglomerate is thick-bedded sandstone with subordinate intercalations of shale, but in the region between Mount Diablo and Coalinga the sandstones are succeeded by 2,000 feet (610 meters) of soft whitish or creamy bituminous shales.

The most notable feature of the Cretaceous (Shasta and Chico) beds is the continuous accumulation in northern California of deltaic marine sediments to a maximum thickness of 5½ miles (8.8 kilometers). As the beds are all shallow-water deposits, this means a continuous depression of the basin pari passu with the load which it was receiving; and the movement is to be correlated with a continuous isostatic rise of the neighboring post-Jurassic mountains under relief of load by erosion. In the southern Coast Ranges, however, the maximum depression appears to have occurred in Chico time.

The end of Cretaceous time was marked by a slight deformation and emergence. The Eocene basin of deposition was in

general the same as that of Cretaceous time but smaller. The unconformity at the base of the Eocene is therefore feebly marked, although the fossils show a pronounced faunal change.

The Eocene formations indicate the continuation of the same general conditions of sedimentation as those which prevailed in the Cretaceous period, except that great sand banks were more characteristic of the sea floor, and the wave-base rhythm of deposits on the submarine slopes of the deltaic embankments was much less pronounced. There was little or no volcanic activity anywhere in the region. Toward the end of the Eocene the basin of sedimentation was full, subsidence for the time having ceased, and the deposits were continental in large part, with intercalated seams of lignite. A renewal of subsidence in the southern Coast Ranges provided the conditions favorable for the accumulation on the sea floor of about 2,000 feet (610 meters) of bituminous shale, made up largely of diatoms and Foraminifera. This occurred in the same general area where bituminous shale had been deposited in Chico time and indicates that a portion of the basin in both Eocene and Cretaceous time had been temporarily cut off from or was remote from deltaic deposition.

The Eocene has been subdivided into several formations, each of which has its lithologic and faunal characteristics. Although they are separated by unconformities the orogenic disturbance and uplift indicated is invariably slight. Sandstones and shales with some conglomerate are the prevailing rock types, and the sections are noteworthy for the absence of limestone. A good deal of greensand occurs in the lower part.

The stratigraphy and structural relations of the Oligocene formations, 6,600 feet (2,012 meters) thick, are still obscure. The rocks are sandstones and shales that were deposited in a marine basin similar to that in which the Cretaceous and Eocene formations already reposed but of smaller area. Oligocene time was brought to an end by moderate but widespread deformation and uplift, inaugurating an erosional interval.

Two groups of formations are included in the Miocene series—the Monterey group and the San Pablo group. The formations of the Monterey group comprise strongly contrasted depositional facies of equivalent age, representing progressive stages of a transgressing sea. As the Monterey transgression extended over the subsiding coast, the water deepened off the eastward-receding shore, so that the pebble beaches and sands of the littoral gave place gradually to an accumulation characteristically pelagic, consisting chiefly of diatom remains with admixture of Radiolaria, Foraminifera, volcanic ash, and fine

sea-borne silt.[1] The edge of this wedge-shaped organic deposit followed the receding littoral as the water deepened and the deposit thickened. The greater part of the pelagic deposit was thus synchronous with the greater part of the underlying littoral deposit.

At various stages of the sedimentary process and at favorable parts of the coast accumulating sand banks extended seaward and covered the edge of the pelagic deposit; and this was followed by a landward encroachment of the pelagic material over the sand banks when the coast still further subsided. This was a recurrent process, so that some sections of the Monterey group consist of alternations of sands and pelagic deposits, each with its characteristic type of fossils. In other sections where the sand banks never extended there were continuous pelagic deposits for thicknesses of several thousand feet. In still other sections the supply of terrigenous detritus was sufficiently abundant to keep the water shallow over large areas and preclude the invasion of the pelagic deposits, and a great thickness of sandstone is the result. The various stratigraphic and paleontologic subdivisions of the Monterey group are depositional facies of one continuous epoch of sedimentation. The remarkable fanglomerates on the coast of southern California, described by Woodford,[2] appear to be represented at one or two localities north of the Santa Barbara Channel and are interesting not only as indicative of arid continental conditions of deposition in early Monterey time, but also as establishing the existence of a land mass to the west of the present coast as a source of the detritus.

The upper Miocene formations are separated from the Monterey on paleontologic grounds under the name San Pablo group. There is no discordance at the base of the San Pablo where it rests on the Monterey, but the basin of deposition was more restricted landward than in Monterey time. Although the San Pablo may be paleontologically separable from the Monterey beds immediately below it, nevertheless it is stratigraphically the product of the Monterey epoch of sedimentation. The conditions of sedimentation that prevailed in the early part of Miocene time, by reason of the transgression of the sea on a subsiding coast, continued without interruption through later Miocene (San Pablo) time.

At numerous localities in the Coast Ranges variable thicknesses of volcanic rocks are intercalated with the strata of Miocene age. These include basaltic, andesitic, and rhyolitic lavas and

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[1] Louderback, G. D., The Monterey series in California: California Univ. Dept. Geology Bull., vol. 7, No. 10, pp. 177-241, 1913.

[2] Woodford, A. O., The San Onofre breccia, its nature and origin: California Univ. Dept. Geology Bull., vol. 15, No. 7, pp. 159-280, 1925.

pyroclastic rocks and some intrusives. None of the occurrences are of great extent, and the thickness of the volcanic element in the stratigraphic column probably does not exceed 1,000 feet (305 meters). Besides this there is in several sections an admixture of fine pumiceous ash in the bituminous shales.

From the foregoing sketch it is apparent that, throughout Cretaceous, Eocene, Oligocene, and Miocene time there existed in the region of the present Coast Ranges a coastal basin of persistent subsidence, subject to partial deformation and segregation into subordinate basins, in which accumulated a vast thickness of sediments. For a large part of the time there was a land mass to the west of this basin. The floor of the basin was depressed unevenly, and as the loading proceeded stresses, not only of isostatic adjustment but also of orogenic compression, were relieved by faults, thrusts, and gentle open folding. At the end of the Miocene these accumulating stresses acting on the weakening crust resulted in a more acute orogenic movement. At this time many though not all of the structural outlines of the Coast Ranges were established. Some large faults originated at various earlier dates and continued to function for the relief of stress through several successive epochs; and some prominent features are due to a later diastrophism. As the degradation of the pre-Pliocene Coast Ranges proceeded several discrete Pliocene basins of sedimentation developed in the region, and they continued to sink pari passu with the loading till they contained many thousand feet of shallow-water deposits. These deposits were in some basins wholly marine, in some wholly continental, and in others alternations of salt and fresh water beds. It is probable that the post-Miocene deformation continued throughout Pliocene time, although perhaps as a more subdued and protracted manifestation. Volcanoes were active in Pliocene time, particularly in the region of San Francisco Bay and northward. The basins of Pliocene accumulation, whether marine or continental, were elongated, troughlike, rather acute depressions, which eventually culminated in sharp synclinal folds of the contained strata. Not uncommonly these synclines are bounded on one side or the other by large faults, on which progressive displacement probably occurred during the filling of the basins throughout Pliocene time.

In several of the Pliocene basins, both marine and continental, sedimentation continued uninterruptedly well into the Pleistocene. In early Pleistocene time the region was subjected to an acute orogenic movement, which completed the diastrophism begun at the end of the Miocene and gave to the Coast Ranges some of their most striking structural features. Pleistocene formations deposited after this orogenic movement are

limited to continental basins of no great extent and to a very narrow strip of the coast. Since the early Pleistocene uplift the Coast Ranges have suffered continuous degradation, and the relief of load thus effected has induced a further general but uneven isostatic uplift of the coast of 1,000 to 2,000 feet (305 to 610 meters) with local depressions where deltaic loading has been active. The isostatic uplift occurred by stages and gave rise to the well-known marine terraces along the coast. The most noteworthy result of depression is San Francisco Bay.

SIERRA NEVADA

The Sierra Nevada has had a complicated history. During Paleozoic and Mesozoic time great thicknesses of sedimentary and volcanic materials accumulated in the region. The sediments were largely of marine origin, and the intercalated volcanic materials consisted of andesitic lavas and pyroclastic rocks and subordinate quantities of rhyolite. There were also many intrusive rocks. At the end of the Jurassic period these materials were all sharply folded and then invaded by plutonic magmas of great volume. As a result of dynamic metamorphism the stratigraphic sequence and structural relations were obscured, and the obscurity was increased by the thermal metamorphism due to the magmatic invasions.

The principal group of rocks of Paleozoic age appears to belong to the Carboniferous system and is known as the Calaveras formation. It includes limestones, quartzites, conglomerates, shales, radiolarian cherts, and various crystalline schists derived from these rocks. The andesitic lavas and pyroclastic materials are mineralogically much altered and are generally changed to amphibolite schists.

The principal Mesozoic formation, known as the Mariposa, is of Upper Jurassic age. It is composed predominantly of slate and shale with intercalated volcanic rocks similar to those of the Calaveras. Between the Calaveras and Mariposa formations there are groups of strata which are referred to the Triassic; but in many sections these are lacking. For example, at Colfax the Mariposa, consisting of alternating tillite and marine slates, rests directly upon a glaciated surface of the Calaveras.

The igneous materials that were intruded into these rocks after the folding—at the end of the Jurassic period or the beginning of the Cretaceous—make up a vast compound batholith of irregular outline. This batholith is now exposed over the greater part of the Sierra Nevada as a result of the removal by long continued erosion of the folded metamorphic rocks that overlay it. It is composed mainly of granitic rocks. Granodiorite, quartz monzonite, and siliceous granite are the predominant types, but there are locally also basic rocks such as

diorite and gabbro. The earliest intrusions apparently consisted mainly of peridotite, which is now altered to serpentine. Dikes of aplite and pegmatite cut all the granitic masses. After the solidification of the intrusive magma quartz veins were formed on shear zones and faults, notably of the great system of gold-bearing quartz veins known as the Mother Lode, which extends in a northwesterly direction through the Calaveras and Mariposa formations. The gold of these veins, however, was deposited after the quartz had filled them.

The mountains that were formed at the end of the Jurassic period as a result of the folding of the Paleozoic and Mesozoic rocks were worn down to comparatively low relief during the Cretaceous period. Finally the streams ceased cutting and began to aggrade. The valleys, especially in the northern part of the region, were filled with gravel to depths of several hundred feet. Not only the stream trenches but the broad benches on both sides were covered. The gravel deposits consisted chiefly of quartz and the harder rocks of the basement complex. There was no volcanic material in them, and they comprised the products of a prolonged erosional concentration of the most resistant materials of the region. Much gold derived from the quartz veins of the Mother Lode system and from many other veins and veinlets was also concentrated in these deposits, and they are the auriferous gravels par excellence of California.

The aggrading rivers took their rise in the same general region as the present summit of the Sierra Nevada, and thus it may be inferred that before the uptilting which produced the great fault-block range there was a low range with a divide approximately coincident with the present crest line.

Aggradation was in progress during the Eocene epoch and continued probably into the Miocene. The decay of the rocks supplied sufficient fine detritus to load the rivers and at the same time release the quartz and other undecomposable constituents of the rock to make the gravel, cobbles, and boulders that gorged the channels and spread out over the flood plains. This congestion of gold-bearing quartz gravel in the river valleys was brought to an end by an outburst of volcanic activity, whereby the region was mantled with rhyolitic ash. This ash, though generally very fine, was sufficiently abundant to exceed the transporting capacity of the streams, so that it accumulated in the valleys, raising and broadening the flood plains. After this deposition of volcanic ash the streams recovered their erosional power and dissected their flood plains. Gorges were cut down through the rhyolitic ash and underlying gravel into the hard rocks of the basement complex. Then these postrhyolite gorges were in turn aggraded, but the gravel that filled them was com-

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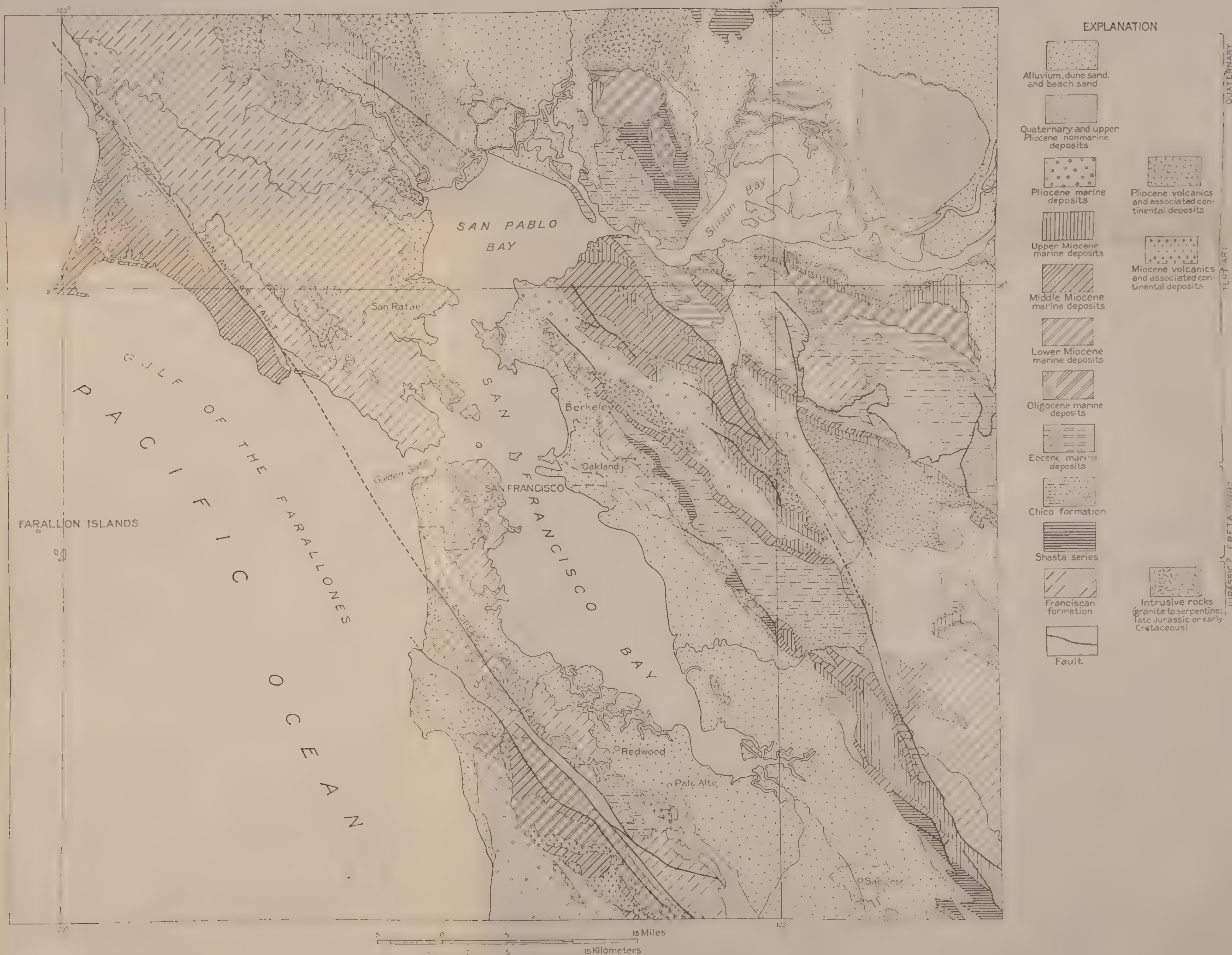
posed in only small proportion of quartz. There were many rhyolitic pebbles, and the softer rocks of the basement were well represented, but the deposits contained little gold. The second period of aggradation was ended by another volcanic outburst. This time the extrusions were andesitic and took the form chiefly of coarse mud flows. The agglomerates thus formed are the thickest and coarsest in the northern part of the Sierra Nevada near the summit, where they have a thickness of about 2,000 feet (610 meters). The accumulation was slow and fitful, for at many levels in the deposit are buried river channels containing well-rounded cobbles and boulders of andesite, indicative of the drainage at various stages of the upbuilding of the surface. These river channels extend down to the edge of the Great Valley, and some of them cross the valley and continue well into the region of the Coast Ranges.

The imposition of the agglomerate upon the western slope of the then low range greatly increased its declivity. The andesitic extrusions were followed by a few isolated flows of basalt and latite, remnants of which constitute table mountains of the present landscape. The date of these latest extrusions is not certain, but they are probably Pliocene.

The various volcanic and fluviatile formations which in Tertiary time were thus successively spread over the region and which are found in remnants to-day on the western slope of the northern Sierra Nevada constitute the "Superjacent series."

In early Pleistocene time the Sierra Nevada was dislocated from the region to the east by faulting and lifted by tilting as a fault-block range. As a consequence the gradients of the westward-flowing streams were steepened and their flow was accelerated. This gave the streams greatly increased corrasive power, and sharp canyons were cut in the uplifted slope. The canyon cutting is still in progress; but at one stage of the process the streams reached base-level and evolved wide-bottomed valleys, after which the vertical corrasion was resumed, owing to a renewal of uplift. The wide-bottomed high valleys are apparent above the brink of the canyon of the American River at several localities—Colfax, for example. Some of them were veneered by thin lava flows before the renewal of canyon cutting, as may be seen in the gorge of the San Joaquin River. It is thus apparent that the uptilting of the Sierra Nevada block comprised two distinct movements with an interval of quiescence between. The recent fault scarps near Genoa, at Mono Lake, and in Owens Valley indicate that the second movement is still in progress. There is no evidence that the "Superjacent series" ever extended over the southern portion of the Sierra Nevada, but many local volcanic outpourings took place there.



GENERAL GEOLOGIC MAP OF THE REGION ABOUT SAN FRANCISCO

From unpublished geologic map of California, compiled by G. W. Stose and Olaf P. Jenkins. The two areas southeast of San Pablo Bay mapped as Pliocene marine deposits are Pliocene continental deposits.

THE SAN FRANCISCO PENINSULA

By Olaf P. Jenkins

INTRODUCTION

Though unique as a geographic unit, containing a city of international fame reached by commerce of the world through the Golden Gate, the San Francisco Peninsula represents geologically a section of the Coast Range province which is typical, considered with reference to structure and geomorphology. (See pl. 3.)

In shape, the peninsula rudely forms a right triangle. The seacoast is the north-south line; the northern vertex is in the broadened head of the peninsula, where the city of San Francisco is situated; and the hypotenuse or east side is the west shore of San Francisco Bay, 35 miles (56 kilometers) in length. The distance from the southern extremity of the bay in a straight line westward to the Pacific Ocean near Half Moon Bay is 20 miles (32 kilometers). The narrowest place in the peninsula is near South San Francisco, where the neck is 5 miles (8 kilometers) broad.

A flat plain with cities, farms, and highways borders the bay, and a more mountainous area, approached by rounded foothills, extends westward to the rugged seacoast. Marshes and meandering sloughs of the bay show well the filling of a sunken area, while in contrast the ocean's wave-cut shore marks a line of erosional destruction. Long bridges span the bay, and in their centers drawbridges are placed across the deeper channel, which is faintly visible through the water from the air.

GEOMORPHIC UNITS

The peninsula may be divided into three geomorphic units, each separated distinctly from the others by faults trending northwest.

1. The Santa Cruz Ranges, rising as high as 3,200 feet (975 meters) above the sea and extending southward from the peninsula for 40 miles (64 kilometers) to Monterey Bay, culminate northward within the peninsula at Montara Mountain, which has an altitude of 1,952 feet (595 meters). It was from this point of vantage that the early Spanish explorers discovered San Francisco Bay.

Montara Mountain, a quartz diorite mass flanked on the north by Tertiary and earlier sediments, overlooks the Pacific Ocean, which has cut a rugged coast immediately south of San Pedro Point. East of this granitic mass lies a series of lower

ridges including Buri-Buri Ridge, alined in a northwesterly course parallel to the great rift occupied by San Andreas and Crystal Springs Lakes. This rift, the San Andreas fault zone, notable for its straight course, trends N. 36° W., cuts the coast line at an angle of about 30°, and disappears beneath the ocean at Mussel Rock but becomes visible again at Bolinas Bay, 20 miles (32 kilometers) to the northwest.

2. Merced Valley, separated from Montara Mountain by the rift and its bordering parallel ridges, occupies a synclinal depression, which is faulted down on the northeast. Its north end has been drowned to form Merced Lake. Several outlying towns of the greater city lie within this valley.

3. San Bruno Mountain, an uplifted fault block, the top of which is 1,315 feet (400 meters) above sea level, lies to the northeast.

North of San Bruno Mountain hills of lesser height continue to the Golden Gate. The eastern shore of the peninsula's head is low and flat, comprising land reclaimed from the shallow bay. The city is built upon both the hills and the reclaimed area.

GEOLOGY

The oldest rocks of the San Francisco Peninsula are intruded by quartz diorite and comprise schists, metamorphic limestones, and quartzite, possibly of Paleozoic age. The quartz diorite of Montara Mountain is generally considered to be older than the Franciscan (Jurassic?), but positive evidence is lacking, because the two formations are separated in this area by the Pilarcitos fault.

The Franciscan group consists of more or less metamorphosed sediments badly crushed and structurally deformed. It is composed for the most part of reddish radiolarian (?) cherts, arkosic sandstones, and some limestones, shales, etc., apparently younger than the schists. It is characterized by intrusions and extrusions of basic and ultrabasic igneous rocks (basalts and diabase), which commonly show ellipsoidal structure, peridotite, gabbro, and pyroxenite, all of which are more or less serpentinized.

Next younger than the Franciscan are the well-bedded and hardened carbonaceous and arenaceous shales of the Lower Cretaceous (Knoxville formation) and the more massive sandstones of the Upper Cretaceous (Chico formation).

The overlying Tertiary sediments are well represented in the Santa Cruz Ranges and the San Francisco Peninsula by nearly a dozen formations ranging in age from Eocene to Pliocene. Basaltic rocks are commonly found in the Miocene.

The gravel of the Santa Clara formation (Pliocene and Pleistocene) is exposed along the foothills southeast of Palo Alto,

and in places remnants of this formation are found locally in the zone of the San Andreas fault. The youngest formations of the area consist of terrace, valley, and stream alluvial deposits and coastal sand dunes.

The geomorphic history of the peninsula is complex, but some of the results of Quaternary faulting and warping of old land surfaces may be viewed on a clear day from a distance. That the San Francisco Bay block was depressed and the streams drowned is a feature of striking importance, both geologically and industrially.

Earth movement took place along the San Andreas rift in 1906. A horizontal displacement of several feet, clearly exhibited by offset fences, roads, etc. (pl. 2, *A*), showed that the Santa Cruz Ranges moved northwestward in relation to the San Francisco area. The destruction of the trunk lines of water mains leading from the reservoirs situated on the rift zone cut off the water supply to San Francisco, so that the fire accompanying the earthquake was uncontrolled. The results of recent study of this and other earthquakes have been taken into consideration by engineers in the construction of the larger buildings and of water-supply projects in this area, in order to minimize destruction in the event of another earth movement.

ITINERARY, PALO ALTO TO SAN FRANCISCO

[See pls. 4, 5]

Santa Clara Valley.—San Jose and Palo Alto are situated in Santa Clara Valley, a flat aggraded interrange basin. Before its submergence a northwestward-flowing stream cut a channel in the rising valley floor. Now the stream channel and most of the valley are drowned, forming the southern extension of San Francisco Bay.

The Mount Hamilton Range lies nearly 30 miles (48 kilometers) east of Palo Alto, on the opposite side of the bay. On a clear day the dome of Lick Observatory can be seen on the highest point in the crest line. To the west, only a few miles distant from the railroad, are the wooded Santa Cruz Ranges. These mountains extend northward on the peninsula that separates the southern arm of the San Francisco Bay from the Pacific Ocean. On the northern head of the peninsula is the city of San Francisco.

Stanford University.—One mile (1.6 kilometers) to the southwest of Palo Alto is Stanford University, founded in 1891. Its presidents have been David Starr Jordan, John Casper Branner, and Ray Lyman Wilbur. The home of Herbert C. Hoover is situated half a mile south of the quadrangle, in the hills of the

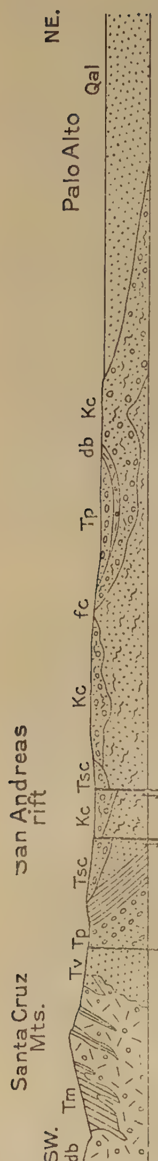


FIGURE 1.—Section from Palo Alto to the summit of the Santa Cruz Range, showing the folds and faults of the several formations about the San Andreas rift. Qal, Alluvium; Tsc, Santa Clara formation (Tertiary); Tp, Purisima formation (Tertiary); Tm, Monterey shale (Tertiary); Tv, Vaqueros formation (Tertiary); db, diabase and basalt; Kc, Chico formation (Cretaceous); fc, Franciscan group (Jurassic?). From U. S. Geol. Survey Bull. 614, fig. 15, 1915

university campus. The geology building is in the southwest corner of the quadrangle.

El Camino Real.—The State highway that follows the old stage road originally laid out by the Mission fathers between San Diego, San Francisco, and northern missions is called El Camino Real. A tall tree (Spanish, palo alto) stands beside the railroad bridge. Under this redwood the Spanish explorer Portola camped in 1769. The tree, *Sequoia sempervirens*, is a lonely survivor of the "bigtrees" of the Coast Ranges.

Redwood City.—Many salt pans and some large white piles of salt may be seen near Redwood City. Farther to the east, next to the bay, is a portland-cement plant that uses recent deposits of oyster shells in place of limestone.

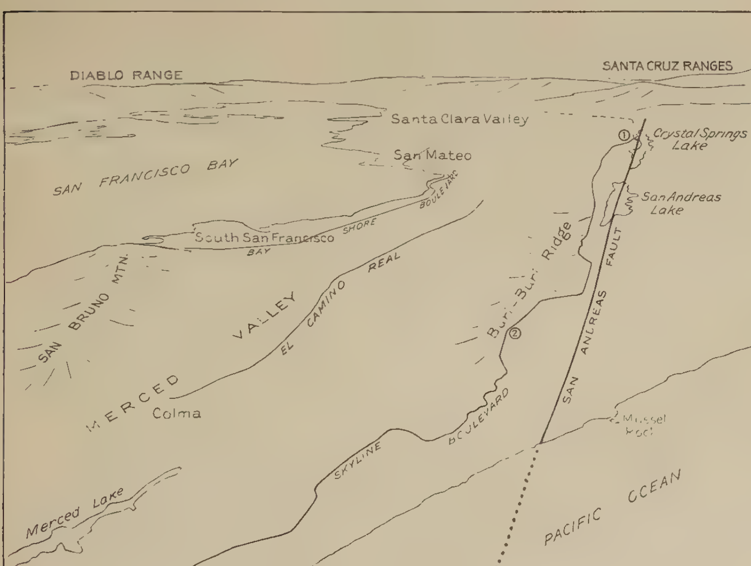
Belmont.—An outlying hill to the southeast of Belmont has been nearly quarried away for Franciscan radiolarian (?) chert, used in the construction of the Bay Shore Boulevard. The oaks of the valley and the chaparral of the foothills west of Belmont are especially characteristic of the natural vegetation of the region, in contrast to the introduced eucalyptus.

Foothills west of Belmont.—On the summit of the foothills west of Belmont is an old erosion surface dissected by rejuvenated drainage courses. Exposures of radiolarian chert and sandstone of the Franciscan group are seen along the roadside. A view of the bay shows two long automobile bridges crossing it. The southern one is Dumbarton Bridge; the northern one San Mateo Bridge. The latter is 10 miles (16 kilometers) long, including the approach.

San Andreas fault rift.—West of these foothills the road enters the great rift zone of the San Andreas fault. Crystal Springs

AIRPLANE VIEW OF SAN FRANCISCO PENINSULA

Looking southeastward directly along the San Andreas rift zone, which is occupied by San Andreas and Crystal Springs Lakes. The excursion route is along the hills above the sea cliffs after following straight courses to the east of the rift. The numbers (1 and 2) indicate localities referred to in the text. Photograph copyright by Fairchild Aerial Surveys (Inc.), Los Angeles.



AIRPLANE VIEW LOOKING NORTHWARD ALONG THE SAN FRANCISCO PENINSULA TOWARD THE GOLDEN GATE

Marin Peninsula in the distance beyond. The granitic white-topped crests of Montara Mountain show in the foreground. San Andreas Lake, occupying the rift zone, lies to the right. Photograph copyright by Fairchild Aerial Surveys (Inc.), Los Angeles.

Lakes, long and narrow artificial reservoirs that store water for the city of San Francisco, occupy the sharp depression along the rift.

Skyline Boulevard.—The road follows the fault zone to the northwest and joins the Skyline Boulevard at the point where the boulevard crosses the rift (No. 3, pl. 4). The rocks exposed in the road cuts on the east side of the rift are principally basaltic intrusives and serpentine but include also Franciscan arkosic sandstones. On the west side of the fault zone are bedded gravel deposits of the Santa Clara formation (Pliocene and Pleistocene), occurring as entrapped slivers in the rift.

As the road leaves the rift zone, it mounts the old surface of the upland again. The sharp cleft of the rift valley to the west is followed a short distance away by the road. In places Franciscan red chert is visible. Native shrubbery, including the toyon, or California holly, grows along the roadside. Exposures show crushed rock of the fault zone. The highway proceeds through softer, sandy fossiliferous sediments of Pliocene age (Merced formation), which overlie unconformably the Franciscan group.

Buri-Buri Ridge.—A fine view of the San Francisco Bay and surrounding country may be seen to the north and east from the top of Buri-Buri Ridge, which parallels the rift, while to the west the observer may catch glimpses of the Pacific Ocean (No. 2, pl. 4). The road follows the crest line of the peninsula.

To the north, South San Francisco, "the industrial city," lies at the foot of San Bruno Mountain within Merced Valley. Across the bay to the northeast is Mount Diablo. To the southwest is Montara Mountain. The quartz diorite of this mountain block lies in fault contact with the Franciscan group.

Seacoast.—Descending, the highway leaves the San Andreas rift zone and follows a ridge above the sea cliffs, with Merced Lake lying to the east, a drowned valley mouth, locked from the ocean by a bar. The great fault rift disappears beneath the ocean, but on a very clear day it may be seen 20 miles (32 kilometers) distant as a notch in the profile of the coast at Bolinas Bay.

Golden Gate.—The highway now follows a sandy coast toward the famous Cliff House, which overlooks the Golden Gate. Turning east toward the Presidio, the traveler should pause a few moments at an observation point, for a full view of the Golden Gate. Mount Tamalpais, altitude 2,604 feet (794 meters), lies north of the Golden Gate, on the Marin Peninsula.

Golden Gate Park.—Continuing above the sea cliffs, the route turns right at the Palace of the Legion of Honor and proceeds toward Golden Gate Park. In the park may be seen the Museum, the California Academy of Sciences, and the Steinhart

Aquarium. Farther on, Seventh Avenue leads to the top of Twin Peaks, the highest point in San Francisco, 925 feet (282 meters) above sea level.

Twin Peaks.—This point affords a fine view of the entire city, the bay, and the mountains beyond. Also, the excellent road-cut exposures show clearly the intricate and complex folding and crumpling of the dark-red Franciscan radiolarian chert, which is remarkably evenly bedded. Intrusions of basic igneous rocks may be seen in some of the exposures.

Presidio.—The route descends by a steep road for another view of the Golden Gate by way of Presidio Parkway. Old Fort Point is the site of the proposed Golden Gate bridge. The winding road along the coast gives a full view of the entrance to San Francisco Bay. The Presidio has been a military post since the Spanish days, as early as 1776.

Berkeley ferry boat.—There is an opportunity for a full view through the Golden Gate from the Berkeley ferry boat. Mount Tamalpais lies to the northwest, Mount Diablo to the east. The boat passes close to Alcatraz Island, to the left, where the Army disciplinary barracks are located. The larger island to the north, Angel Island, is the site of the quarantine station. Yerba Buena, or Goat Island, lies just between Oakland and San Francisco. A proposed bay bridge is to make use of this island, tunneling through its center. All these islands and the heads of the peninsulas are composed of rocks of the Franciscan group.

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SAN FRANCISCO BAY

By William Morris Davis

Imagine two subparallel crustal blocks of deformed structure and moderate relief to be raised on the sides of a depressed trough block more than 100 miles (161 kilometers) in length and from 5 to 15 miles (8 to 24 kilometers) in width. In consequence of these displacements the raised blocks are now maturely dissected members of the California Coast Ranges, and the depressed trough is occupied by a long and flat intermont plain of aggrada-

tion little above sea level. Let these three features be traversed by a trunk river which, receiving the Sacramento and San Joaquin Rivers on the great interior plain of California, cuts through the inner range in a narrow notch, the Carquinez Gorge, flows southwestward across the low plain, cuts through the outer range in a deeper notch, the Golden Gorge, and thus reaches the Pacific.

Now imagine the district to have been moderately depressed. The waters of the sea thereupon entered the Golden Gorge and transformed it into the famous strait known as the Golden Gate, a name proposed by Frémont in 1844, before gold was discovered in California; the severed parts of the outer range between the bay and the ocean, north and south of the Golden Gate, constitute the Marin and San Francisco Peninsulas. Part of the smooth, low-lying interrange plain was at the same time flooded by sea water, which thus formed the broad and relatively shallow San Francisco Bay, 50 miles (80 kilometers) in length, extending farther south than north of the Golden Gate.

This great embayed area was discovered from the land side by Spanish explorers who came overland northward from Mexico in 1772; the Mission of San Francisco was established next south of the Golden Gate in 1776. When the Golden Gate was formed, Carquinez Gorge was drowned in Carquinez Strait, by which the waters of the large, shallow lower bay invaded the interior plain for a short distance and formed the small and still shallower uppermost cove, or Suisun (soo-soon′) Bay. The depression of the region by which the bay was produced must have been relatively local, for the transverse valleys of the Russian River, 35 miles (56 kilometers) to the north, and of the Pajaro River, 50 miles (80 kilometers) to the south, both of which cut through an outer Coast Range, are not drowned in bay-mouth straits, and the plains back of their ranges are not converted into bays.

Outside of the Golden Gate strong cliffs have been cut by the ocean waves where they beat violently on the new shore line of that part of the outer range known as the Marin Peninsula, next north of the Golden Gate. Short interspur ravines are there left "hanging" high above sea level, as may be well seen in the fine view across the Golden Gate from the northwestern angle of the San Francisco Peninsula. Abundant sands, derived chiefly from cliffed headlands to the south, have been drifted northward by a backset eddy[3] of the main southward-flowing

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[3] This backset eddy and several others of similar origin on the California coast are aided whenever southwest winds blow over them; but that they are primarily due to reaction from the main southward-flowing current, an important member of the north Pacific circulation, is shown by their occurrence only south of coastal salients that hold the current offshore.

ocean current, which is locally held offshore by a salient of the coast northwest of the Golden Gate; thus an extensive beach has been formed along the ocean side of the San Francisco Peninsula, and under the prevailing westerly winds extensive dunes have invaded the low coastal slope south of the Golden Gate. The dunes were waste lands in the early history of San Francisco but have now been largely reclaimed in Golden Gate Park and in growing residential districts.

The northward drift of the beach sands has built a shallow submarine bar across the Golden Gate; but the bar has been pushed seaward by the ebb tide from the bay, so that it forms a curve with a radius of about 5 miles (8 kilometers), with depths of 22 to 35 feet (6.7 to 10.7 meters). In the strait itself a maximum depth of 414 feet (126 meters) is found. A long sand reef, known as Stinson Beach, supplied from the submarine bar, has closed Bolinas Bay, next northwest of the strait. This body of water and its counterpart, Tomales Bay, farther north, are of significance as submerged parts of valleys that were, in pre-submergence times, worn down along the belt of crushed rock in the fault zone of the famous San Andreas rift. Marine terraces of slight emergence are seen on the shores of these bays.

The piedmont lowlands, which formerly sloped gently down from the inner side of the outer range to the intermont aggraded plain now submerged in the bay, appear to have suffered the greatest loss of area along the east side of Marin Peninsula, north of the Golden Gate, and hence the greatest submergence may be inferred to have taken place thereabouts. Slightly larger areas of piedmont lowlands survive along the east side of the San Francisco Peninsula, where the earliest great city of the Pacific coast has grown. Its present water front has been artificially built out into the shallow bay; and it is interesting to note that the filled-in area covers the hulks of several vessels, a few of three or four hundred which, arriving about the time of the gold rush of 1849, were grounded on the low-tide flats and abandoned by both passengers and crew, who all hurried inland to the "diggings."

The main bay is subdivided by a peninsular ridge, 10 miles (16 kilometers) in length, a small member of the Coast Ranges, into San Francisco Bay proper on the southwest and San Pablo Bay on the northeast. Adjacent areas of clear greenish water of flood tide and of yellowish muddy water from Suisun Bay are often strongly contrasted in San Pablo Bay. Several rocky mounts, perhaps worn-down chips of small Coast Range fault blocks, which formerly interrupted the intermont plain, now rise in the bay as little islands. Waves in the bay are relatively weak, as the water there is only from 25 to 50 feet (7.6 to 15

meters) deep. Where slanting mountain spurs reach the shore they have been but slightly cut back in low cliffs; and the cliff recession here is less than the advance of marshy delta flats in many small interspur coves. Still larger marshy flats are seen where streams enter the north and south ends of the bay from the not submerged parts of the intermont plain.

The greatest encroachment on the submerged areas since their depression is found where the Sacramento and San Joaquin Rivers, which lost their trunk stream at the time of maximum submergence, are now reuniting in distributary channels among the extensive and marshy delta lands at the head of Suisun Bay. The encroachment is believed to have been significantly accelerated by the downwash of detritus from the deposits of auriferous gravel on the flanks of the Sierra Nevada, which were extensively hydraulicked between 1852 and 1884. An amount of detritus sufficient to fill the entire bay would be but a small fraction of that supplied chiefly from the valleys of the Sierra Nevada and deposited in the interrange trough known as the Great Valley of California during its aggradation in presubmergence time. The Sierra Nevada still contains a vastly greater volume of rock than has been removed during the excavation of its existing valleys. In a short geologic epoch the bay will be completely refilled if no further movement of depression takes place. Then the submarine bar, which is now held away from the mouth of the Golden Gate by the ebb tide from the unfilled bay, will stretch directly across the mouth of an alluvial valley floor in the restored Golden Gorge; and the bay will be only a short-lived episode of the recent past.

THE BERKELEY HILLS

By Bruce L. Clark

INTRODUCTION

The Berkeley Hills (pl. 6, *A*), as viewed from the city of San Francisco, form a low but prominent range having a fairly even crest and a rather steeply sloping, highly dissected western front. This range, a division of the Coast Ranges of California, has a length of about 15 miles (24 kilometers) and a width of 10 miles (16 kilometers). In the ridge immediately east of Berkeley the highest point is Grizzly Peak, 1,930 feet (588 meters) above sea level. In this region the Coast Range province is about 40 miles (64 kilometers) wide; between the Berkeley Hills and the eastern margin of the province at the Great Valley of California are the San Ramon Valley and the Diablo Range, with Mount Diablo, the highest peak in this immediate vicinity (altitude 3,849 feet, or 1,173 meters), as its culminating point.

At the western base of the Berkeley Hills and separated from them by the great Haywards fault is a low-standing area, upon which are situated the main parts of the cities of Berkeley and Oakland and, farther west, San Francisco Bay. The whole of the Coast Range province is traversed by faults, of which the most pronounced have a northwesterly trend. The major topographic features of the province have to a large extent been developed by movements of the various blocks along these faults, and each block possesses distinctive geologic and structural features. The San Francisco Bay area is underlain by rocks of the Jurassic (?) Franciscan group, but the Berkeley Hills are composed chiefly of Cretaceous, Tertiary, and Quaternary strata.

FORMATIONS

For the purpose of field orientation the principal characters of the formations exposed along the western front of the Berkeley Hills are outlined as follows:

Jurassic(?).—The oldest rocks belong to the Franciscan group and are exposed at the western base of the hills north and south of Berkeley. The sediments, which are widely exposed in the San Francisco Bay area to the west, comprise brownish or greenish arkosic sandstones, shales, and white, red, green, and black thin-banded cherts. These strata are intruded by many bodies of serpentine and a few of diabase, and at several horizons there are eruptive ellipsoidal basalts. Intense hydrothermal alteration of the serpentine has produced at many localities a brownish silica-carbonate rock; Founders Rock, at the northeast corner of the University of California campus, is an example. About the contacts of many of the serpentine bodies are aureoles composed of various types of schists, of which bluish glaucophane schists are the most characteristic.

Cretaceous.—Along the lower slopes of the Berkeley Hills, above the Franciscan rocks, are dark-gray argillaceous and arenaceous shales of Knoxville age (Lower Cretaceous, in part possibly late Jurassic). The contact between the Knoxville and Franciscan is thought by some geologists to be depositional, by others to be faulted. Overlying the Knoxville is the Oakland conglomerate, which has a thickness of about 1,000 feet (305 meters) and includes the *Aucella crassicollis* zone. Arkosic sandstones are interbedded with the conglomerates. Above the Oakland conglomerate lie dark-gray shales, brown arkosic sandstones, and local conglomerates. The few fossils obtained from strata above the Knoxville are Upper Cretaceous types corresponding to those found in the Chico formation of neighboring regions.

A. BERKELEY HILLS, EAST OF UNIVERSITY OF CALIFORNIA

The low-standing San Francisco Bay block in the foreground (occupied by the cities of Berkeley and Oakland) is underlain by rocks of the Jurassic (?) Franciscan group. The lower slopes of the hills are eroded in Cretaceous strata (1); the crest is formed by Pliocene volcanic rocks, chiefly lava flows (2). Between are Pliocene and Miocene sediments (3). The Haywards fault forms the western boundary of the hills. Photograph by G. E. Russell, San Francisco.

B. UPLAND FLANKING YOSEMITE VALLEY

The summit of El Capitan is marked by a cross. Photograph by F. C. Calkins. From U. S. Geol. Survey Prof. Paper 160, pl. 9, *A*, 1930.

Tertiary.—The principal formations exposed along the route to be followed by the excursion are of Tertiary age.

Resting on the Chico with angular unconformity are middle Miocene beds correlated with the Monterey group of other areas; locally they are known as the Claremont shale. These strata are well exposed along Skyline Ridge and comprise thin-bedded brownish or yellowish cherts separated by thin layers of chocolate-brown siliceous shales; white and dark-gray sandstones and a few lentils of limestone are also present. The thickness of this series is about 1,000 feet (305 meters). Because of their superior resistance to erosion, the cherts have formed prominent ridges and knobs along the west front of the Berkeley Hills.

The Pliocene formations include continental sediments and volcanic rocks of various types, which aggregate about 6,000 feet (1,829 meters) in thickness. From the base of the section up, the following units are recognized:

1. Orinda formation: Separated from the Monterey group by an erosional unconformity are fluvial sandstone, conglomerate, and some clay, about 500 feet (152 meters) thick. The clastic beds are for the most part poorly lithified.

2. Moraga formation: This formation, which has a thickness of about 1,200 feet (366 meters), is composed of andesitic and basaltic flows and tuffs with intercalated beds of conglomerate, sandstone, clay, and limestone. The strata are well exposed along the western front of Grizzly Peak and on the bold Frowning Ridge, on which this peak is located.

3. Siesta formation: Overlying the Moraga are fluvial and lacustrine sediments about 200 feet (61 meters) thick, which include sandstone, carbonaceous and tuffaceous shale, and limestone. This formation is exposed in the synclinal valley east of Grizzly Peak.

4. Bald Peak volcanics: Basaltic flows, generally referred to as the Bald Peak basalt.

STRUCTURE

In the section of Berkeley Hills to be crossed by the excursion the structure is essentially synclinal, though many complications are introduced by large faults that traverse the region. The western slope of the Berkeley Hills, culminating in Frowning Ridge, with Grizzly Peak as its highest point, is the western limb of the syncline. The valley lying east of Grizzly Peak and trending northwest has been etched by streams in the trough of the syncline. The eastern limb rises to form San Pablo Ridge.

ITINERARY

A. From the hills about a quarter of a mile (0.4 kilometer) north of the university campus there is a good general view of the San Francisco Bay region. The Golden Gate is almost due west. A little south of it are the San Bruno and Montara Mountain blocks, and still farther south are the Santa Cruz Mountains. North of the Golden Gate is a series of prominent fault blocks, the highest of which is the Mount Tamalpais block.

The point of observation is on the eastern edge of the Hayward fault zone which in this vicinity has a width of about half a mile (0.8 kilometer). Pliocene andesitic lavas are exposed here. A short distance to the north are two rhyolite plugs intruded along the Haywards fault zone during late Pliocene or early Pleistocene time.

There are great variations in the character of the front of the Berkeley Hills north and south of the point of observation. Just back of the university there is a sharp, eroded fault scarp at which the old surface of the San Francisco Bay area is cut off abruptly. In the immediate vicinity of this point the old surface has been warped up irregularly, and bordering the front are a series of small fault blocks tilted at various angles. These are composed of all the different types of rocks found on both sides of the fault. A little farther north the old surface slopes up to the hills and there is no scarp.

B. Near the top of Grizzly Peak are excellent exposures of the Pliocene Moraga volcanic rocks and interbedded sediments. Between points A and B is the Wildcat Canyon fault. Overlying the Moraga formation east of this point are light-gray limestones and dark-gray shales of the Siesta formation, and below the Moraga are the sandstones, conglomerates, and variegated reddish and greenish shales of the Orinda formation.

Southward from this point there is a good view of all the formations in this section. The oldest beds next to the Haywards fault are Cretaceous. Overlying them are the Claremont shales, of middle Miocene age. The Wildcat Canyon fault cuts through these shales. Above the shales is the Orinda formation.

C. Quarry several miles south of point B. After leaving the road where the Berkeley Hills lavas are exposed, the Skyline Boulevard, south of the Tunnel Road, will be traversed. This road follows the strike of the middle Miocene shales for several miles. The Wildcat Canyon fault cuts and parallels the shales along most of this distance, and in this zone the rocks are badly broken and deformed. At many points along the road are irregular sandstone intrusions and dikes which have been forced up into the deformed shales. In the quarry the Miocene

Monterey group, consisting of alternating thin beds of shale and chert, is exposed. Andesitic dikes and dikes of sandstone are also present.

D. Here there is a very good view of the Berkeley Hills and of Mount Diablo, which is cut by the largest known low-angled fault in this part of the State. After the road passes through the Miocene strata the formations exposed between points D and E are of Cretaceous age. Basal Cretaceous conglomerates appear in several road cuts.

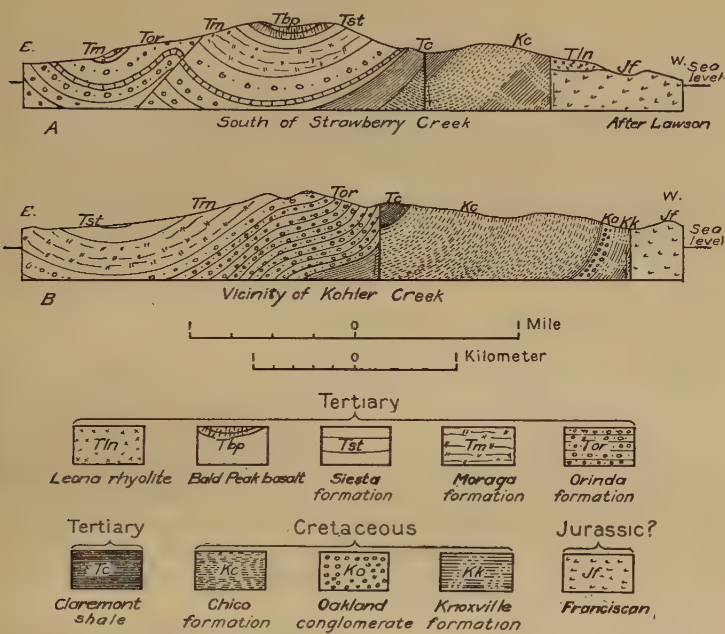

FIGURE 2.—Cross sections showing structure of Berkeley Hills

E. This point is on the east side of the Haywards fault zone, which in this vicinity is several miles in width. Immediately to the west and south the serpentines of the Franciscan group form the top of the ridge. Near the south end of this ridge is a quarry in rhyolite that has been intruded along the Haywards fault zone. Many small fault blocks along the fault zone are well exposed in the area toward the south and west.

After leaving this point the excursion will proceed to the north in one of the rift valleys of the Haywards fault zone and finally across the fault zone into the city of Oakland.

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GEOGRAPHY AND GEOLOGY OF THE SIERRA NEVADA

By François E. Matthes

GEOGRAPHY

Extent and general character.—The Sierra Nevada consists of an immense tilted block sloping gently to the southwest and breaking off abruptly on the northeast in an imposing fault-line escarpment. It is the largest block range in the United States, 430 miles (692 kilometers) in length and on the average 70 miles (113 kilometers) in breadth. In areal extent it is comparable to all of the Swiss and French Alps and most of the Italian Alps together.

The Sierra Nevada is also the loftiest range in the United States. It bears the highest summit south of Alaska—Mount Whitney (14,497 feet, or 4,420 meters)—and as a whole it stands higher above its immediate base than any other range in this country, being 11,000 feet (3,353 meters) above Owens Valley and nearly 14,000 feet (4,267 meters) above the Great Valley of California. From Mount Whitney the crest declines to the north, the highest peaks at the north end reaching but little above 7,000 feet (2,134 meters). The eastern escarpment, which becomes increasingly irregular and diversified by spur ranges toward the north end, there stands only about 3,800 feet (1,158 meters) high.

Throughout its length the crest of the Sierra Nevada is unbroken by any deep gaps. This circumstance together with the boldness of the escarpment makes the Sierra Nevada a more formidable obstacle to east-west travel than any part of the Rocky Mountain system of similar length, as the emigrants bound for the gold fields of California in 1849 discovered to their sorrow.

As the crest line is but a few miles from the eastern base of the range, only short, small streams descend the eastern escarpment, but down the western slope flow rivers 60 to 100 miles (97 to 160 kilometers) in length. These are arranged, with the sole exception of the Kern, roughly parallel to one another and at right angles to the axis of the range.

All the rivers are deeply intrenched. The canyon of the Merced River (of which the Yosemite Valley is an integral part) attains a maximum depth of 4,000 feet (1,219 meters). The Kings River and its two main branches, in the south half of the range, have canyons 6,000 to 7,000 feet (1,829 to 2,134 meters) in depth—that is, considerably deeper than the Grand Canyon of the Colorado River.

The major corrugations of the Sierra Nevada do not all trend down the western slope. The more prominent ridges trend northwestward, roughly parallel to the main crest. These subsidiary crests, 2,000 to 3,000 feet (610 to 914 meters) above the general level of the surface, deflect the master streams and determine the courses of many tributaries regardless of the general slant of the block. They are most numerous in the upper portion of the range, adding greatly to the scenic beauty of that alpine region known as the High Sierra.

Climate.—Because of its position at right angles to the moisture-bearing winds that blow in from the Pacific Ocean, the Sierra Nevada receives heavy precipitation on its western slope but relatively little on its eastern escarpment. The broad valleys of the Great Basin, lying in the "wind shadow" of the range, are mostly waterless deserts.

The bulk of the precipitation on the Sierra Nevada (the "snowy sawtooth range" of the Spanish padres) falls in the winter in the form of snow. It is most abundant at altitudes between 5,000 and 9,000 feet (1,524 and 2,743 meters), the snowfall there, according to the records of the United States Weather Bureau, aggregating from 20 to 40 feet (6 to 12 meters) a year and sometimes reaching the amazing total of 60 feet (18 meters). These heavy winter snows effectually preclude any permanent settlement of the higher parts of the range. The few forest rangers and employees of hydroelectric companies who remain on duty in winter have to use snowshoes or skis for travel and dog sleds for transportation. To prevent its tracks from being blocked by snowdrifts and avalanches the Southern Pacific Railroad finds it necessary at the higher levels to maintain mile-long snow sheds built of heavy timber.

The summers in the Sierra Nevada, on the other hand, are extremely dry. Rainless periods of two or three months are the rule, though occasional thunderstorms may occur, especially in the High Sierra. Camping without tents is a common practice. So enjoyable and salubrious is the summer climate in the higher parts of the range that they have become a mecca for vacation seekers. Half a million people annually visit the Yosemite National Park alone, and thousands flock to the other portions of the range that are now accessible by highways.

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Owing to the long periods of insolation during the summer the range is wholly divested of snow each year, yet in the shady cirques in the High Sierra a number of small glaciers and névé fields remain perennially.

Life zones.—In ascending the western slope of the Sierra Nevada the traveler can not fail to be impressed by the marked changes in the character and make-up of the vegetation that occur at successively higher levels. In the semiarid foothills he sees only the scanty growth characteristic of the biologist's Upper Sonoran life zone—thin grass, chaparral (an aggregate of small-leaved bushes among which the red-stemmed manzanita (*Arctostaphylos*) is especially prominent), scattered evergreen oaks, and digger pines (*Pinus sabiniana*).

Toward the 3,000-foot (914-meter) level this vegetation becomes denser and finally merges with the majestic forests of the Transition life zone. Here flourish the yellow pine (*Pinus ponderosa*), the Jeffrey pine (*Pinus jeffreyi*), the sugar pine (*Pinus lambertiana*), and the incense cedar (*Libocedrus decurrens*)—all valuable lumber trees attaining great size and great height. Dispersed among them, in groups or groves, stand the "bigtrees" (*Sequoia gigantea*), which reach 200 to 300 feet (61 to 91 meters) in height and 20 feet (6 meters) in diameter.

The Canadian life zone, from 7,000 to 9,000 feet (2,134 to 2,743 meters) in altitude, is characterized by large stands of lodgepole pine (*Pinus murrayana*) and groves of fir. Between altitudes of 9,000 and 11,000 feet (2,743 and 3,353 meters) is the Hudsonian life zone, whose distinctive trees are the western white pine (*Pinus monticola*), the alpine hemlock (*Tsuga mertensiana*), and the white-bark pine (*Pinus albicaulis*), which grows storm-twisted, often prostrate, up to the extreme timber line. Above this line, in the Alpine zone, the peaks stand practically bare.

The forest belt abounds in wild life, especially in the national parks, where hunting is prohibited. Deer, bear, and coyotes are plentiful, but mountain sheep are rare, and the grizzly bear (which California features on its State emblem) is now extinct. The puma or mountain lion is still an occasional undesired visitor in the grazing districts. Rodents, including several species of squirrel and chipmunk, are extremely abundant. There are many species of birds, ranging from the golden eagle to the humming bird, but the great California condor, once the king of Sierra bird life, is extinct. Mountain quail are numerous, and the diving water ouzel is often seen along cascading brooks. Rattlesnakes occur here and there but are decreasing in number. Trout of several different species, including the native golden

trout, abound in lakes and streams, mainly as a result of systematic distribution from fish hatcheries.

Natural resources and industries.—Mining for gold and other minerals is still going on at a number of localities, chiefly in the Mother Lode belt. Marble of good quality is quarried near Sonora. Lumbering is carried on less extensively than formerly. The greater part of the forest land is now under the administration of the Forest Service, which regulates cutting with a view to conserving the forests and the waters of the range.

The water resources of the Sierra Nevada are to-day probably its most important economic asset. Storage reservoirs have been built on all the larger streams to impound the abundant water derived from the winter snows. The water is used for irrigation in the lowlands adjoining the range and for the development of electric power on a large scale. One hydroelectric project alone, on the upper San Joaquin River, is reputed to represent a total outlay exceeding the cost of the Panama Canal. Several California cities derive their water supply from rivers in the Sierra Nevada. All the streams on the eastern escarpment as far north as Mono Lake are under the control of the city of Los Angeles, and the water from them is piped to the city reservoirs through an aqueduct more than 200 miles (322 kilometers) in length. The city of San Francisco has built a costly dam transforming the Hetch Hetchy Valley into a storage reservoir and is now spending large sums on tunnels through which the water is to be conveyed down the west slope of the range.

GEOLOGIC STRUCTURE

The Sierra block is composed mainly of granitic rocks forming a vast compound batholith. It contains also large masses of metamorphic rocks of Paleozoic and Mesozoic age—remnants of an earlier mountain system into whose folds the magmas of the batholith were intruded. (See fig. 3.) The metamorphic rocks are most abundant in the north half of the range, where they form two belts—a broad belt paralleling the western foothills and a narrower discontinuous belt along the crest and the eastern escarpment. The south half of the range is composed almost wholly of granitic rocks. Only a few isolated bodies of metamorphic rocks occur widely scattered through it. These and similar isolated bodies in the north half are either roof pendants or remnants of partitions between neighboring intrusions.

The main belt of metamorphic rocks on the lower slope of the range is made up of two unconformably related formations that

FIGURE 3.—Generalized cross section of central Sierra Nevada. *A*, Mariposa slates; *B*, Calaveras formation; *C*, *C*, roof pendants of metamorphic rock in the batholith; *D*, metamorphic rocks on crest of range. A small volcanic cone is shown in the zone of faulting at the east base of the range. The vertical scale is exaggerated. From U. S. Geol. Survey Prof. Paper 160, fig. 2, 1930

extend roughly parallel to each other with northwesterly strikes and steep northeasterly dips. These are the Calaveras formation, of Carboniferous age, on the east, and the Mariposa slate, of Upper Jurassic age, on the west. The strata of both formations are compressed into tight, partly isoclinal folds. Those of the Calaveras formation are, however, much more complexly folded than those of the Mariposa, and their rocks are more highly metamorphic, having suffered deformation twice, whereas the Mariposa rocks have suffered deformation only once. Fossils are rare in both formations.

The rocks of the Calaveras formation consist largely of black phyllite and subordinate amounts of quartzite, marble, and radiolarian chert. Interbedded with these sedimentary rocks are considerable bodies of amphibolite schist and other altered volcanic materials, also masses of foliated diorite and granite, which were intruded probably toward the end of the Paleozoic era.

The Mariposa formation consists mainly of carbonaceous slate, graywacke, and some limestone, conglomerate, and tillite. Folded in with these are masses of greenstone representing altered basaltic and andesitic tuff and agglomerate, which may possibly be in part of Triassic age.

The metamorphic rocks on the crest of the range are chiefly quartzites, argillites, and schists. The age of these rocks and of those in the scattered roof pendants is unknown.

Cutting the metamorphic rocks on the lower slope are a number of small bodies of gabbro and several long, narrow belts of serpentine alined in a

northwestward-trending strip, which were intruded somewhat in advance of the granitic rocks composing the main batholith. The granitic rocks consist predominantly of granodiorites, quartz monzonites, and siliceous granites. Some of the individual intrusive masses occupy areas hundreds of square miles in extent. Diorite and gabbro occur as a rule only in small local masses. All these rocks are cut by numerous dikes of aplite and pegmatite. Veins of lamprophyre and quartz occur in certain areas.

The outlines of the batholith are extremely irregular. Some of the projecting masses at its margins appear to have forced their way into the adjoining metamorphic rocks, bending the strata out of their normal northwesterly alinement. The contacts with the metamorphic rocks are as a rule sharply defined, and evidences of assimilation are relatively rare.

The structure of the granitic rocks is remarkable for the wide variations in the spacing of the joints and especially for the total absence of fracture planes in masses measuring hundreds and even thousands of feet in horizontal and vertical extent. The rock in these masses appears to have suffered repeated fracturing during its cooling stages and is cut by intersecting dikes of aplite and pegmatite, but it is now wholly undivided and forms immense monoliths. These monoliths exfoliate at their exposed surfaces in concentrically curving shells from a few inches to 6 feet (1.8 meters) in thickness. Long-continued exfoliation has resulted in smoothly rounded dome and whaleback forms which, being almost devoid of vegetation, stand out conspicuously in the landscape. These exfoliation forms are not to be confounded with roches moutonnées, rounded by overriding glaciers. Some of them are in unglaciated portions of the range, and of those within the glaciated portion several are definitely known not to have been overtopped by the ancient glaciers.

The cause of this exfoliation on a large scale is still obscure. By some geologists the liberation of expansive stresses within the granite as the result of the progressive removal of superincumbent loads of rock by erosion is regarded as the most probable primary cause. Diurnal insolation and secular warming are in all probability auxiliary causes.

Related to the batholith but confined almost wholly to a narrow zone of overthrusting in the lower belt of metamorphic rocks is the great system of gold-bearing quartz veins known as the Mother Lode. From the vicinity of Mariposa these veins extend in a northwesterly direction for a distance of 120 miles (193 kilometers). They represent the final phase of magmatic activity in the region of the batholith.

At the western foothills the hard rocks of the Sierra Nevada slope under the overlapping sediments of the Great Valley, which

are derived from the range. The oldest are the sandy shales of the Knoxville formation, of Lower Cretaceous age. Above these are the sandstones of the Chico formation, of Upper Cretaceous age. Overlying these in turn are sands, clays, and tuffs of the Ione formation, of Eocene age. These Ione sediments probably represent in part delta deposits that were built by the rivers in the shallow sea which during Eocene time covered the basin of the Great Valley. Upstream these sediments grade into the auriferous gravel deposits of the Eocene epoch, which remain preserved in some of the ancient river beds of the Sierra Nevada.

In the north half of the range the metamorphic and intrusive rocks, known collectively as the "Bedrock complex," are broadly mantled over by volcanic materials of Tertiary age, generally referred to as the "Superjacent series." The older of the extrusives, confined mostly to ancient valleys, consist of rhyolitic tuffs of late Eocene and perhaps also Oligocene age, but the bulk of the volcanic mantle consists of andesitic agglomerate of late Miocene age. This material, together with local beds of andesitic lava and tuff, attains thicknesses as great as 2,000 feet (610 meters), especially in the higher parts of the range, where the volcanic vents presumably were situated. A few flows of latite and basalt of late Miocene or early Pliocene age represent the last outpourings of this great epoch of volcanic activity.

In the central and southern portions of the range, on the other hand, there are widely scattered volcanic necks and small patches of andesitic and basaltic lava which obscure only small areas of the crystalline rocks. Some of the extrusions are of Miocene age, others Pliocene, and still others of Pleistocene interglacial age.

The zone of faulting at the east base of the range is marked by numerous small cones and flows of rhyolite and basalt, in part Pleistocene and in part Recent.

Glacial moraines of the Pleistocene epoch are abundant throughout the upper half of the west slope of the Sierra Nevada and at the mouths of all the larger canyons that gash its eastern escarpment.

In the Yosemite region the writer has distinguished three series of moraines indicative of three stages of glaciation that were separated by long intervals of partial or total deglaciation. The earliest or Glacier Point stage is represented only by rows of surviving boulders composed of very durable types of rock. The next younger or El Portal stage is represented by massive moraines of great extent, yet obscure in form and in part dissected by stream erosion. The granitic boulders in them are so much decomposed that they are readily cut with pick or shovel.

The third and latest stage, which is tentatively correlated with the Wisconsin stage of the continental ice (Würm), is recorded by less extensive but well-preserved, sharp-crested moraines containing a large percentage of unweathered granite boulders. In many valleys the lateral moraines of this stage occur in a double-crested series, indicating two glacial maxima that followed one upon the other in relatively quick succession—presumably in an early Wisconsin substage and a late Wisconsin substage.

On the east side of the Sierra Nevada, Blackwelder has divided the moraines into four series recording as many separate stages of glaciation. These he has named the McGee, Sherwin, Tahoe, and Tioga. The McGee is correlative probably with the Glacier Point, and the Sherwin with the El Portal. The Tahoe and the Tioga appear to be the equivalents of the writer's early Wisconsin and late Wisconsin, respectively, but Blackwelder prefers to regard the Tahoe as the equivalent of the Iowan. Both observers believe the Sherwin or El Portal to be not younger than the Illinoian (Riss). Both suspect its voluminous moraines to embody the record of two stages not yet clearly differentiated, corresponding presumably to the Kansan (Mindel) and the Illinoian (Riss). The McGee or Glacier Point stage they would tentatively correlate with the Nebraskan (Günz).

In addition to the Pleistocene moraines the writer has found at the mouths of many empty cirques along the crest of the range extremely fresh moraines which he believes to be of Recent age—indeed, of late historic age. They are comparable to those fresh moraines in the Alps of Savoy and Switzerland, which are definitely known to date from the 19th century.

OROGENIC HISTORY AND GEOMORPHOLOGY

At least two ancient mountain systems have in turn occupied the place on which the present Sierra fault block stands. This fact is evident from the structure of the metamorphic rocks; the first mountain system, which was presumably of Appalachian type, is indicated in the complexly folded strata of the Calaveras formation; the second mountain system, more clearly of Appalachian type, is indicated in the simpler, northwestward-trending folds of the Mariposa slate. The first system was formed probably toward the end of the Carboniferous period. After partial demolition by prolonged erosion, it subsided under the sea of Mesozoic time, to be covered by the Mariposa beds. The second system was formed either at the end of the Jurassic period or at the beginning of the Cretaceous, and it was under

and into the folds of this system that the magmas of the compound batholith were intruded.

Throughout the Cretaceous period the parallel mountain ridges were subject to erosion. Over large areas, especially in the southern half of the Sierra region, they were worn down completely, and the metamorphic rocks of which they were composed were stripped from the granite. The region as a whole was reduced to a lowland, but several ridges composed of very durable rocks remained standing with moderate height, so that certain northwestward-trending elements were perpetuated in the topography.

Early in the Eocene epoch the Sierra region was gently upwarped along an axis coinciding approximately with the present crest line, and its seaward slope was steepened. As a consequence the drainage system was rearranged. The southwestward-flowing streams grew at the expense of streams flowing in other directions, and thus there came into existence a series of master streams that flowed roughly parallel to one another down the slope and transverse to the northwestward-trending ridges. Eventually these new master streams reapportioned among themselves the longitudinal drainage between the ridges.

Later in the Eocene epoch, as a result of renewed uplifts, the master streams intrenched themselves, so that their channels came to lie fully 2,000 feet (610 meters) below the tops of the ridges. It was in these channels that the auriferous gravel accumulated. Volcanic eruptions from vents in the crestal region supervened, causing the channels to be buried under large quantities of rhyolitic tuff. Some of this material was removed by the streams, but further eruptions undid their work, and thus volcanism and erosion acted in alternation probably well into Oligocene time.

There ensued a long period of practically uninterrupted erosion that lasted until the later part of the Miocene epoch. During this time the entire Sierra region acquired a postmature topography characterized by broadly open valleys of low gradient and rounded divides of approximately equal height. This was the postmature surface which by some geologists has been called the "Sierra peneplain." Large tracts of this Miocene surface remain preserved to-day in the form of billowy intercanyon uplands, especially in the areas of massive granitic rocks where erosion has proceeded at a very slow rate. (See fig. 4.) Above these uplands, 2,000 to 3,000 feet (610 to 914 meters) in height, stand the northwestward-trending ridges characteristic of the High Sierra, which are residuals from the early Tertiary topography. The tabular tops of some of the peaks are isolated remnants of the early Eocene surface. Similar

residual ridges with northwesterly trend stand also in the Mother Lode belt, on the lower slope of the range. Such are Peñon Blanco and Moccasin Peak, southwest of Priest, and the Bear Mountains, west of Angels Camp and San Andreas.

In the northern half of the Sierra Nevada the Miocene surface is largely buried under volcanic flows. There the later part of the Miocene epoch was a time of great volcanic activity. Intermittent floods of andesitic mud, sometimes of lava, poured down the western slope, first burying the river channels, then filling the valleys, and ultimately coalescing over the divides. On the surface of the volcanic materials the waters reorganized into new rivers that carved new valleys with more direct courses down the slope than the buried valleys had. Down one of these new valleys cut in the andesite poured the final flow of latite which, in

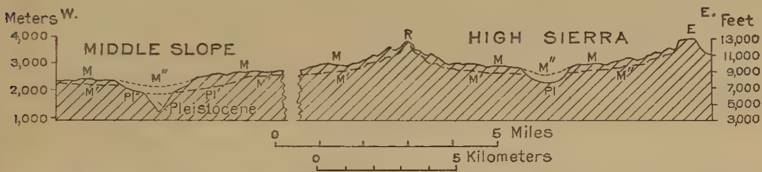

FIGURE 4.—Idealized profile showing features produced by successive cycles of erosion. E, Tabular remnant of Eocene surface on high residual peak; R, residual peak no longer bearing remnants of Eocene surface; M, M, Miocene surface preserved on intercanyon uplands; M′, M′, longitudinal profiles of hanging valleys of Miocene cycle (glaciated in High Sierra); M″, M″, reconstructed cross profiles of main valleys of Miocene cycle; Pl, main valley of Pliocene cycle (glaciated); Pl′, longitudinal profile of hanging valley of Pliocene cycle; Pl″, reconstructed cross profile of main valley of Pliocene cycle; Pleistocene, gorge of Pleistocene cycle (unglaciated). Vertical scale same as horizontal scale

the vicinity of Sonora, now stands above the general level of the landscape in Table Mountain.

The age determination of what is here called the Miocene surface of erosion rests primarily upon paleontologic evidence obtained in the Table Mountain district. Impressions of leaves and bones and teeth of mammals found in interandesitic stream channels near Columbia appear to indicate a late Miocene or possibly early Pliocene age. The relations of Table Mountain and the stream channel under it to the geomorphic features of the district are shown in Figure 5.

The end of the Miocene epoch in the Sierra region was marked by strong crustal deformation accompanied by faulting. The eastern margin of the region was raised about 3,000 feet (914 meters) above its previous level; the escarpment came into existence, though probably with only moderate height; and the

Sierra Nevada gained the aspect of a gently tilted crust block. As a result of the tilting the master streams on the western slope began vigorously to intrench themselves. So rapidly did they cut that their lesser tributaries were unable to keep pace with them and were left pouring from hanging valleys. This was true especially of the longitudinal streams between the northwestward-trending ridges, whose courses lay practically at right angles to the direction of the tilting and therefore remained almost unsteepened.

Throughout the Pliocene epoch, which was a time of relative crustal stability, the cycle of erosion continued, so that eventually the master streams cut down to grade, and their canyons, 1,000 to 1,500 feet (305 to 457 meters) in depth, widened gradually to mature valleys. Many of the hanging side valleys were completely trenched, but those underlain by massive granite were cut only by short gulches at their mouths and largely retained their hanging aspect.

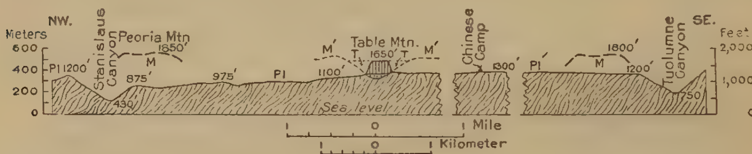

FIGURE 5.—Section through Table Mountain region. Pl, Pliocene surface of erosion developed on unresistant slates and volcanic rocks of the Mariposa formation; M, residual mountains bearing remnants of Miocene surface; M′, reconstructed hills on Miocene surface flanking the ancient valley through which the latite of Table Mountain flowed; T, reconstructed portions of Table Mountain flow. Beneath the columnar latite of Table Mountain is the gravel of the buried river channel, which has been mined for gold. The Stanislaus and Tuolumne Canyons were cut during the Pleistocene cycle. Vertical scale is twice the horizontal scale

Early in the Pleistocene epoch orogenic forces again asserted themselves and there ensued those tremendous and rapid uplifts that gave the Sierra Nevada its present great height. The crest, in the central part of the range, was raised about 6,000 feet (1,829 meters); in the southern part it was raised even more. As a consequence the master streams on the western slope were again rejuvenated. With greater vigor than before they intrenched themselves, producing narrow, steep-sided gorges. Throughout Quaternary time, down to the present day, the trenching has continued, the gorges gaining in depth until they now measure 1,500 to 2,000 feet (457 to 610 meters) in depth.

Again, the lesser side streams, for the same reason as before, lagged behind in gorge cutting, and so the main canyons came to have a second set of hanging side valleys 500 to 1,000 feet (152

to 350 meters) below the first set. The hanging valleys of this second or Pliocene set are naturally much better preserved than those of the first or Miocene set.

Not all the Quaternary gorges in the main canyons have been cut all the way up to the sources of the rivers. Owing mainly to the presence of large bodies of massive granite that is extremely resistant to erosion, some of the gorges head at a considerable distance from the crest of the range, and as a consequence the upper stretches of the Pliocene valleys remain untrenched. The Quaternary gorge of the Merced River, for instance, heads (or, to be more precise, headed prior to glaciation) at the upper end of the Yosemite Valley, 18 miles (29 kilometers) from the source of the river on Mount Lyell. The Little Yosemite and the upper Merced Canyon above it, therefore, represent an untrenched stretch of the Merced's Pliocene valley (remodeled by glacial action). The Quaternary gorge of the Tuolumne River (tu-ol′um-ne) heads below the Tuolumne Meadows, 15 miles (24 kilometers) from Mount Lyell; and the Tuolumne Meadows themselves (through which the route to the Tioga Pass is laid) are in the untrenched upper portion of the Pliocene valley of the Tuolumne.

During the Pleistocene epoch the entire High Sierra, comprising a belt 25 to 30 miles (40 to 48 kilometers) in breadth on the upper slope of the range, was repeatedly mantled with glaciers. As a consequence, while the master streams were cutting their sharply V-shaped gorges in the lower slope, their untrenched Pliocene valleys above were being vigorously glaciated and transformed to broadly U-shaped troughs. The little side valleys on the Miocene uplands, which already were hanging above the Pliocene main valleys, became the paths of tributary glaciers, and, as they suffered less excavation than the main valleys, their discordance with these was generally increased. The heads of the little Miocene valleys carved in the flanks of the northwestward-trending crests of the High Sierra, being the sources of the glaciers, were resculptured into amphitheaterlike cirques. Some of these cirques bit deeply into the tabular remnants of the Eocene surface that persisted on the higher peaks, but those tabular remnants themselves for the most part escaped glaciation and were subject only to nivation. Thus it will be seen that practically all of the glacial sculpture, which gives the High Sierra its distinctive, scenic aspect, has been developed from the earlier topography—the Pliocene and Miocene.

The great trunk glaciers extended, especially during the periods of maximum glaciation, far beyond the borders of the High Sierra and invaded the Pleistocene gorges below. They attained lengths ranging from 30 to 60 miles (48 to 96 kilometers), but even the longest did not reach within 30 miles of

the foothills. It was in the upper portions of the Pleistocene gorges that the glaciers attained the greatest thickness and greatest excavating power. The changes they brought about in the configuration of the gorges are most striking in areas where glacial quarrying was facilitated by the jointing of the rocks. The Yosemite Valley, the Hetch Hetchy Valley, and the other capacious valleys of the Yosemite type have all been developed in portions of Pleistocene gorges where the rocks are prevailingly well jointed. In the areas of massive granite, on the other hand, glacial action was limited largely to abrasion, and there the changes produced are in places astonishingly slight. Thus it is that the broad yosemites contrast with narrow portals and gorges immediately above or below them, which the glaciers were unable to enlarge to characteristic glacial forms.

In contrast with those of the western slope, the features of the eastern escarpment of the Sierra Nevada are nearly all of Quaternary age. Only at the higher levels are there, associated with them, hanging-valley heads that are clearly older, dating back to Pliocene or in some valleys even to Miocene time. The escarpment is probably in large part of early Pleistocene origin. There is reason to believe that it did not assume its present imposing height, as a result of the downfaulting of the Owens Valley graben, until after the Sierra Nevada had suffered its first period of glaciation. For, whereas the moraines of the Sherwin, Tahoe, and Tioga stages, as defined by Blackwelder, lie at the mouths of the deep canyons that gash the mountain front, certain moraines belonging to Blackwelder's earliest (McGee) stage are situated on a high shoulder, overlooking the escarpment, where they could have been deposited only before the canyons were cut to their present depth.

The downfaulting of Owens Valley, though on a colossal scale, was attended by only minor volcanic outbreaks. Small cinder cones, some rhyolitic, others basaltic, arose, and local extrusions of lava occurred at many places along the base of the escarpment. Since then only feeble movements have taken place in the zone of faulting. The fault scarps of Pleistocene and Recent time are as a rule only a few tens of feet (a few meters) high. In most of them further subsidence of the valley blocks rather than renewed elevation of the Sierra block appears to be indicated. The youngest scarps were produced at the time of the great Owens Valley earthquake of 1872. They are from 8 to 25 feet (2.4 to 7.6 meters) high and extend for several miles along the foot of the range in the vicinity of Lone Pine.

Postglacial weathering has proceeded with extreme slowness in the areas of the massive granite. As a consequence the

canyons and cirques there are remarkably fresh and clean in appearance, and taluses of rock débris are very small; only in the areas of well-jointed igneous rocks and thin-bedded, closely fractured metamorphic rocks do the cliffs present the usual more or less ruinous aspect, and only in such areas are the taluses long and high.

The level floors of several valleys, notably the Yosemite, Little Yosemite, and Hetch Hetchy, consist of Recent alluvium filling basins excavated by the Pleistocene glaciers, but the great majority of the glacial lake basins in the Sierra Nevada remain unfilled, owing to the small amount of débris carried by the streams, and as a result there are hundreds of picturesque lakelets that add greatly to the charm of the landscape.

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STRUCTURE OF THE SIERRA NEVADA BATHOLITH

By Ernst Cloos

GENERAL GEOLOGY

Flanked on the northeast and southwest by belts of metamorphic rocks of Paleozoic and Mesozoic age, the central Sierra Nevada consists of a large compound batholith of late Jurassic or early Cretaceous granodiorite and smaller masses of basic and siliceous intrusive rocks. The batholith (the term is used without implications as to its mode of emplacement) represents a dynamic unit, although composed of many more or less independent, intrusive units.

The excursion up the western slope of the range and through the Yosemite region will traverse the southwestern wall rocks and a variety of igneous rocks belonging to the batholith. As the structure of the batholith is of special interest in view of the interpretation given, it is outlined below in some detail.

STRUCTURAL GEOLOGY

In order to determine the mechanics of emplacement, it is desirable to group the observable features according to their modes of formation. In the field it is possible to distinguish the following structural elements:

1. Elements of the viscous or plastic phase:
   - A. With one pronounced long axis (linear parallelism)—
     - Parallel orientation of minerals (hornblende, titanite).
     - Parallel spindle-shaped inclusions.
     - Linear arrangement of schlieren.
   - B. With two approximately equal and one distinctly shorter axis (platy parallelism)—
     - Parallel platy minerals (mica, feldspar).
     - Parallel platy inclusions (discoid xenoliths and autoliths).
     - Parallel schlieren (schlieren, rich in mica and hornblende; light schlieren, accumulations of feldspar, scarce in dark minerals).
   - C. Equidimensional inclusions in chains or swarms.

2. Elements of the phase of incipient rigidity: Zones of movement, flexures with drag of foliation.
3. Elements of the solid or ruptural phase:
   - A. Dikes on marginal thrust planes, marginal thrust planes with striae (confined to the neighborhood of contacts).
   - B. Tension partings (planes of stretching) partly filled with dike material.
   - C. Normal open joints (filled with aplite, pegmatite, lamprophyre, quartz).
   - D. Normal closed barren joints—joint fans, feather joints, shear zones with feather joints, regional joints.
   - E. Exfoliation.

In interpreting these features and deducing the mechanics of intrusion from them, it is to be noted that the directions of local or regional movement, as deduced from each group of features, indicate one and the same general mode of emplacement—a fact which greatly increases the reliability of the conclusions.

The orientation of the elements of the plastic stage is shown on the map and cross section in Plate 7. Many thousand readings were taken with compass and clinometer, plotted on maps, and then somewhat generalized for better understanding. A list of good exposures, in which the main features can be easily studied, is attached at the end of this paper for the convenience of future visitors to the area.

The results of the structural survey may be outlined as follows:

The igneous complex.—Two main intrusive masses can be distinguished between the western contact near El Portal and the eastern contact at Tioga Pass—a western main mass, which reaches from El Portal to a line extending from Sentinel Dome to Mount Hoffmann, and an eastern main mass, which reaches from this line to the Tioga Pass. The western main mass is composed of a series of intrusions of gabbro, diorite, and granite, which have followed one another at close intervals. The earliest intrusion was a basic one and now floats in a medium-grained granodiorite, the El Capitan granite of Calkins (39).[4] Large bodies of El Capitan granite are surrounded by the later Sentinel granodiorite, in which the flow structure follows the contacts.

The flow structure of the western main mass, as a whole, forms a dome, the elements dipping toward the contacts and being locally horizontal in the center. The joints are arranged in the form of a fan, dipping into the intrusive complex from the western and eastern contacts.

A large, broken septum of metamorphic rocks (marble, quartzite, schist) separates the western main mass from the eastern main mass. This septum, which extends from Sentinel Dome

[4] Numbers in parentheses refer to bibliography, p. 45.

to Mount Hoffmann, is believed to be a part of the former side wall rather than a roof pendant. It dips vertically and extends for many miles in a northeasterly direction, and in one place it is exposed for more than 2,000 feet (610 meters) vertically.

The eastern main mass is composed of a mantle of quartz monzonite (Half Dome quartz monzonite) and a younger core of porphyritic granite (Cathedral Peak granite), in the center of which is a still younger intrusion of Johnson granite porphyry.

The outer mantle of quartz monzonite contains an enormous number of dark inclusions, xenoliths, and autoliths. All the inclusions are oriented, and the direction of their elongation at different points serves as an index of the flow structure. Xenoliths become more numerous toward the contacts, but autholiths are widespread over the whole area occupied by this rock.

The flow structure of the eastern main mass forms a second dome and attests to the structural independence of this structural unit. The eastern unit is younger than the western unit. (See pl. 7.) The schlieren form a dome whose crown is approximately in the center of the last intrusion (of Johnson granite porphyry), whence they dip toward the contacts. The flow lines thus form an arch, which reaches from the septum, on the west, to the eastern contact near Tioga Pass.

The joint systems in the eastern mass are arranged in a fan very similar to the fan in the western mass but much more pronounced. Joints near the western contact dip to the east, joints near the eastern contact dip to the west, and those in the center are mostly vertical.

Regional joints are abundant and form one of the striking features of the region.

The flow structure of practically all the projecting parts of the batholith, which are situated west of a northwest-southeast line through El Portal, dips east. Flow lines form a monoclinal zone and pitch parallel to the linear stretching of the Calaveras formation. The intrusive mass south of Mariposa is of special interest in this connection, as it forms a tonguelike offshoot into the Mariposa formation. The flow structure dips into the batholith, in places at an angle as low as 30°. The Mother Lode zone begins in this mass of granodiorite.

The contacts.—The external contacts (between the batholith and the wall rocks) are everywhere sharp and well defined; the internal contacts (between the constituent intrusions) are gradational wherever the intrusions followed one another at close intervals.

Of great significance is the fact that the western contact at many places dips to the east under the intrusive. The dip is

MAP AND STRUCTURE SECTION OF A PORTION OF THE SIERRA NEVADA BATHOLITH
After Geol. Rundschau, Band 22, pl. 2.

especially low (only 30°–40° E.) near Bridgeport, south of Mariposa, where it is well exposed in the bed of Mariposa Creek.

The eastern contact dips in part under the country rock, in part under the batholith (Kuna Crest).

Marginal thrust planes and tension cracks.—A characteristic feature of the breaking stage consists of the marginal thrust planes near the main contacts. Large joints, partly filled with dike material and mostly covered with striae, dip away from the contact at very low angles (30°–40°). Every one of the planes shows a displacement toward the contact. Tension joints are similar partings, but the displacement on them is away from the contact.

A similar zone of marginal thrust planes, though less pronounced, exists along the western contact of the eastern main mass (following the septum)—for instance, in the south wall of Glacier Point. The displacements there are directed toward the west.

The most remarkable zone of marginal thrusting is in the Mother Lode belt. Here quartz veins follow the thrust planes and dip east. A very pronounced joint system follows the same direction, and the thrust veins therefore show that the Mother Lode belt is the mechanical western contact of the Sierra Nevada batholith. The marginal thrust planes are placed like feather joints in relation to the upward movement along the contact zone.

GENERAL CONCLUSIONS

The dome-shaped schlieren, which plunge toward the contacts, are believed to be due to the rising of two structural centers of semiliquid magma, the marginal portions having been retarded at the contact zones. The tendency of the flow lines to pitch within the schlieren surfaces, along the steepest inclination, is regarded as additional proof that the congealing magma was drawn out principally in the upward direction.

The arrangement of joints more or less at right angles to such flow lines also indicates an elongation of the arch, due to the same agency and in identical directions.

Marginal thrusts, observed on both sides of the intrusion, effect an upward elongation of the entire mass, lending further weight to the assumed method of emplacement. The development of ore veins along the Mother Lode belt may be a special feature of this latest stage in the igneous history.

The apparent lack of magmatic assimilation is also in harmony with this general conception.

A succession of intrusions, beginning in the Mother Lode belt, has opened and gradually widened a gap. The earlier intrusions

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preferred stratigraphic or tectonic boundaries—for instance, the boundary between amphibolite schist and Calaveras formation, or the Mother Lode itself. The later intrusions of granodiorite took advantage of boundaries between previous intrusions and the wall rock, leaving a thin septum of metamorphic rock intact.

The uniform and regular dome-shaped internal structure does not give any indications of sunken blocks or assimilated roof pendants. The constituent intrusions appear to have been differentiated before entering the final resting place.

The regions of uniform internal structure grew gradually with increasing rigidity. The schlieren dome was overlapped by the arch of flow lines, and the arch in turn overlapped by joint fans. As the rigidity increased, regional joints became more and more important, until finally the whole area between the eastern fault zone and the Mother Lode reacted as one block.

LOCALITIES OF INTEREST

Localities where features of interest to the visitor can be seen are indicated below.

Linear flow structure, spindle-shaped autoliths, linear orientation of hornblende crystals, flat-dip underlying contacts: South of Bridgeport, 4 miles (6.4 kilometers) from Mariposa toward Merced, in the canyon of Mariposa Creek.

Primary flexures, thrusts, flat westward-dipping joints and pegmatites, platy parallelism of inclusions and schlieren, feather joints, etc.: Humbug Creek, south of Wawona road, and Mariposa.

Mother Lode joints, thrusts, quartz veins dipping east, stretched conglomerates in the Calaveras formation, undeformed conglomerates in the Mariposa formation, containing fossils: On the road from Jacksonville to Groveland (Priests grade road) and on the south side of Moccasin Creek, opposite Moccasin power house.

Contact between western mass and Calaveras, thrusts, dikes, joints, linear flow structure, faults: In the surroundings of the Cliff House, about 25 miles (40 kilometers) east of Groveland on the Big Oak Flat road.

Swarms of inclusions in horizontal orientation: Cascade Falls, in Yosemite Valley.

Inclusions, dikes, joints, several types of granite: Wawona road to Inspiration Point, Yosemite Valley.

Western wing of the joint fan of the eastern main mass: North wall of Yosemite Valley, behind Ahwahnee Hotel.

Thrusts toward the west, schlieren, joints, inclusions: Ledge trail to Glacier Point.

Relation between septum (marble), eastern and western main masses, joint fans, thrusts, schlieren, flow structure: North of Tenaya Lake.

Gradational contact between the mantle granite and the core, schlieren in the core, foliation in the mantle: Road from Tenaya Lake to the Tuolumne Meadows.

Marginal thrusts toward the east, schlieren, inclusions, linear flow structure, border gneiss, stretched conglomerates in the eastern wall rock, slickensides, sharp contacts between mantle and core granite: Tioga Pass, south wall of Mammoth Mountain-Vogelsang area. The best locality to study all the mechanical and petrographic relations in the east is the eastern slope of Mount Conness, north of the botanical garden near Camp Tioga.

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THE MOTHER LODE SYSTEM

By Adolph Knopf

INTRODUCTION

The Mother Lode belt of California (fig. 6) is a long, narrow strip on the western foothills of the Sierra Nevada, in which is inclosed a more or less continuous series of gold deposits. It is a mile (1.6 kilometers) wide and 120 miles (193 kilometers) long. Because of the great, wall-like masses of quartz that crop out at intervals along the belt, there grew up during pioneer days the belief that a single great quartz vein, the Mother Lode, extends

continuously from one end of the belt to the other. As the gold deposits are not continuous, however, and consist not only of quartz veins but also of various other kinds of gold deposits, the term Mother Lode system is more appropriate.

The total output to the end of 1931 is estimated to amount to $225,000,000. More than half of this gold has come from a 10-mile (16-kilometer) segment of the belt, extending from Plymouth to Jackson, in Amador County.

Mining began in 1849 near the town of Mariposa, at the south end of the belt. The greatest vertical depth so far attained is 5,100 feet (1,554 meters), and the Mother Lode still holds the distinction of having the deepest gold mines in North America. The ore in the bottom levels is on the average as good as that mined on the upper levels. Mining on the Mother Lode belt is favored by nearness to supply centers, by good transportation facilities, labor supply, and climatic conditions, and by the slow increase of rock temperature in depth—1° F. for every 150 feet (46 meters). These advantages are partly offset in the mining of the quartz veins by the moderate gold content of the ore, the moderate size of the ore bodies, and the high cost of timbering, due to heavy ground.

GENERAL GEOLOGY

In late Jurassic or early Cretaceous time the region of the Sierra Nevada felt the onset of the Cordilleran revolution. The rocks were isoclinally folded and then were invaded by a succession of plutonic rocks, beginning with peridotite, which was soon altered to serpentine, and ending with granodiorite. The remarkable albitite dikes near the Tuolumne River were also intruded probably at this time. At the end of this epoch of igneous activity the gold deposits were formed. Since the Cordilleran revolution the gold belt has remained above sea level; and during that long span of time erosion has stripped off several thousand feet of rock.

The northern part of the Mother Lode belt as far south as the Gwin mine, in Calaveras County, 6 miles (9.6 kilometers) south of Jackson, is inclosed in alternating Mariposa slate and associated greenstone. From the Gwin mine southward as far as the Tuolumne River the lode is chiefly in green schist; it there enters serpentine, in which it continues to Coulterville, where it enters the Mariposa slate, and it continues in this formation until it is terminated by the granodiorite south of Mariposa. The differences in geologic environment of the gold deposits determine certain differences in the nature of the gold deposits themselves.

FIGURE 6.—Geologic map of Mother Lode belt from Plymouth to Jackson (42,[5] fig. 3)

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[5] Numbers in parentheses refer to bibliography, p. 60.

The statistics of output prove that the gold has been markedly localized in certain portions of the belt, notably in the 10-mile (16-kilometer) segment in Amador County, at Angels Camp and Carson Hill in Calaveras County, and in a segment south of Jamestown, Tuolumne County.

The ores are of low or moderate grade, averaging $7 a ton. The very low-grade ores formerly mined, ranging from $2 to $3 a ton, are no longer worked. The gold as it occurs in the ores ranges in fineness from 839 to 899 parts per thousand, its fineness apparently depending on the nature of the associated sulphide or telluride. Sulphides make between 1 and 2 per cent of the quartz ore but are two or three times more abundant in the ore bodies of mineralized country rock. They consist almost wholly of pyrite, with minor arsenopyrite, sphalerite, galena, chalcopyrite, and tetrahedrite. The telluride petzite appears to be restricted to the portion of the Mother Lode in Calaveras and Tuolumne Counties. Arsenopyrite is fairly common in Amador County. Galena and petzite indicate good ore, but the other sulphides are indifferent indicators.

The gold deposits are of two principal kinds—quartz veins and bodies of mineralized country rock. The quartz veins generally occur as systems of parallel or acutely intersecting veins; as many as four veins have been worked in a single mine. Not many of them can be definitely traced for more than a few thousand feet. They cut the inclosing rocks at an acute angle in both strike and dip. They fill fissures that were formed by reverse faulting, in some of which the displacement amounts to 375 feet (114 meters). These fissures appear to be auxiliary fractures accompanying a great reverse fault that bounds the Mother Lode belt on the east.

Structurally the veins do not conform to the idea that they follow lines of least resistance; they make an acute angle with the well-developed cleavage of the slate, and they leave slate to pass into massive greenstone, and vice versa. (See fig. 7.) Where this happens the vein is markedly deflected or refracted, and this refraction is so conspicuous a structural feature of the veins of Amador County that a rough value of 1.4 for the index of refraction from slate to greenstone was computed.

The veins swell and pinch abruptly; in the lenticular expansions the filling is quartz; at the edges of lenses, either along the strike or on the dip, the massive quartz filling becomes more and more admixed with slate or pinches down to a gouge-filled fissure. Banding or ribboning is common in veins that are inclosed in slate or schist and is invariably parallel to the walls of the veins; locally the divergence between ribboning and bedding is as much as 45°.

The ore occurs in shoots that are generally short but persistent in depth. The shoots as a rule have a steep pitch or "rake," which may be either north or south. The ore shoots are considerably wider than adjacent portions of the vein, as well as containing more gold to the ton. Furthermore, the shoots consist more solidly of quartz, and where the massive quartz filling

FIGURE 7.—Structural features of a quartz vein in slate (42, fig. 4). 1, Slate; 2, graywacke bed; 3, quartz; 4, gouge; 5, stringer zone in disturbed slate

of the ore shoot frays out into a stringer lode it becomes poor in gold. Unfortunately, however, large bodies of quartz do not necessarily make ore even if they occur along fissures that elsewhere contain ore shoots. Most of the known ore shoots cropped out at the surface, but some have been discovered whose tops were as deep as 3,300 feet (1,006 meters). Intersection and

branching of veins favored but did not everywhere determine the development of ore shoots.

The gold is believed to have come from a deep-seated magmatic source, the quartz came largely from the adjacent wall rock, and the water by which these substances were carried in solution came partly from the magma and largely from the meteoric circulation. As the thermal water rising in a fissure issues at the earth's surface only at certain orifices, such localized efflux would determine more rapidly moving threads of current in the fissure; all other water in the fissure would be stagnant or nearly stagnant. Only those portions of the fissure in which the ore-depositing solution was actively flowing would become the sites of gold deposition.

It is unsafe to generalize for the whole Mother Lode belt as to the influence of the nature of the wall rocks on the tenor of the ore. Valuable ore bodies have formed in rocks of many kinds. Probably the only valid generalization is the one made by Ransome—that paying veins may occur in any rock with the possible exception of serpentine. However, the slate appears to be more favorable than the greenstone, and veins wholly inclosed in greenstone are likely to be of low grade. Although the favorable character of the slate has been ascribed to its carbonaceous content, the real explanation may be that the slate delivered quartz less rapidly to the veins than the greenstone or other rocks; the ore, so to speak, was less diluted with quartz.

The ore bodies of mineralized country rock comprise the so-called gray ore and the mineralized schist. They occur either adjacent to quartz veins or in broad zones of fissuring. The gray ore is the result of hydrothermal attack on the augitic greenstone; it consists of ankerite, sericite, albite, quartz, pyrite, and generally some arsenopyrite and contains enough gold to be profitably workable. Many of the shoots were large and averaged as high as $8 a ton. These shoots generally adjoin thin quartz veins or are in the wedge between two intersecting veins. The tenor of the gray ore can be determined only by assays. There may well be large deposits of gray ore undiscovered, but guides to their discovery are unknown.

The mineralized schist ore bodies consist of pyritic sericite-ankerite schist and are the results of the alteration of amphibolite and chlorite schists. They are generally ramified with quartz-ankerite veinlets. They are of low grade as a rule, carrying from $2 to $3 a ton, but one of the highest-grade ore bodies ever mined on the Mother Lode belt, the hanging-wall ore body of the Morgan-Melones mine, on Carson Hill, is a pyritic ankeritized schist. Many of these ore bodies form either the footwall or the hanging wall of a large, thick barren quartz

vein. At Carson Hill the schists in the footwall of the thick barren quartz vein made a very low-grade ore body, whereas the schists in the hanging wall made the high-grade ore body already mentioned.

The wall rocks of the Mother Lode veins have been profoundly altered by the ore-forming processes. Large volumes of rock have thereby been transformed. Carbonatization (ankeritization) was the chief effect, regardless of whether the rocks were slate, graywacke, quartzite, conglomerate, greenstone, amphibolite schist, chlorite schist, talc schist, or serpentine. Sericite, albite, pyrite, and arsenopyrite were also commonly formed by chemical attack on the wall rocks. Gold also migrated into the wall rocks, as already described.

Serpentine and the augitic greenstones were the most susceptible to ankeritization. The ankeritized serpentine, which is particularly distinctive of the southern part of the lode, makes up belts hundreds of feet thick, generally tinted a delicate green by the presence of the chromiferous potassium mica mariposite. The black slates because of their fine grain and carbonaceous pigment seem to be unaffected, but microscopic and chemical analyses prove that they too have been greatly altered, chiefly by ankeritization. Moreover, the microscope shows that the ankerite augen that have formed in the slates by replacement have been caused to rotate while they were growing, which indicates that the compressive forces that opened the vein fissures were active during the time when the vein stuff was being deposited.

Great quantities of carbon dioxide were added to the wall rocks, and correspondingly great quantities of silica were eliminated from them. This silica was more than enough to supply the quartz in the Mother Lode veins, and this fact leads to the surmise that the somewhat unfavorable effect of serpentine and greenstone on the veins in them may have been due to the rapidity with which they supplied quartz to the growing veins.

The veins can best be explained as having grown by successive enlargement along fissures that were from time to time reopened by renewal of movement along them. To some extent the force of crystallization of the growing quartz may have aided in producing the ribbon structure of the veins. The quartz of the veins was supplied from the wall rocks; the gold, sulphur, arsenic, carbon dioxide, and certain other constituents were probably supplied by exhalations along with steam that issued at a high temperature from a deep-seated consolidating granitic magma and that also furnished a part of the thermal energy of the ore-forming solutions. After these exhalations had condensed to water that carried the other constituents dissolved in

it the motive power for causing this "magmatic water" to rise was doubtless the gravity potential of a meteoric circulation whose paths were determined by the fissure systems. These processes took place near the end of the epoch of plutonic intrusion that marked the final stage of the Cordilleran revolution in late Jurassic or early Cretaceous time.

TYPICAL MINES

KENNEDY MINE

The Kennedy mine is in Amador County, 1 mile (1.6 kilometers) north of Jackson. It is worked through a vertical shaft to the 4,800-foot (1,463-meter) level, and by an auxiliary inclined winze a depth of 5,100 feet (1,554 meters) is attained.

The Kennedy vein fills a reverse-fault fissure and cuts at an acute angle, both in strike and in dip, a series of more steeply dipping Mariposa slate and greenstones of Mariposa age. These inclosing rocks may be divided into six belts, three of which consist predominantly of slate and three of greenstone.

The vein crops out 120 feet (37 meters) west of the old North shaft on the Jackson-Martell road. As here exposed it is a thin and rather insignificant quartz vein, striking N. 10° E. and dipping steeply to the east. Black slate forms the hanging wall and mineralized greenstone the footwall. As the vein continues south, its dip flattens to 30° or less and greenstone forms both walls.

That the Kennedy vein in depth cuts through successive belts of rocks of differing character is shown in the vertical section of Figure 8.

A feature of the vein, not shown in Figure 8, is that below the 2,400-foot (732-meter) level in the northern part of the mine the vein splits into two branches. Examination of the junction of the two branches, known locally as the west and east splices, in the stopes proves conclusively that they are contemporaneous.

The portions of the vein that are being mined are lenses, the largest 200 feet (61 meters) in length and of diverse width, the maximum stope width having been 112 feet (34 meters). The average thickness throughout the stope length is 15 feet (4.5 meters). The lenses pass, within a very short distance, into a thin stringer lode, or even into a gouge vein without quartz filling. These lenses constitute the ore shoots and are remarkably persistent in depth, in view of their comparatively short horizontal extent. They pitch slightly to the south. In addition to the shoot on the main vein, both branches into which the main vein splits generally carry ore. All three shoots are present at or near the junction of the branches with the main vein.

The ore exposed on the deeper levels is chiefly a massive coarse quartz and carries a very small quantity of sulphides, which consist mainly of pyrite with insignificant quantities of sphalerite and galena and "traces" of arsenopyrite. Free gold is occasionally found. A silvery micaceous mineral, probably damourite, occurs locally in the quartz and usually indicates a good grade of ore. Apatite, as a gangue mineral from the 3,900-

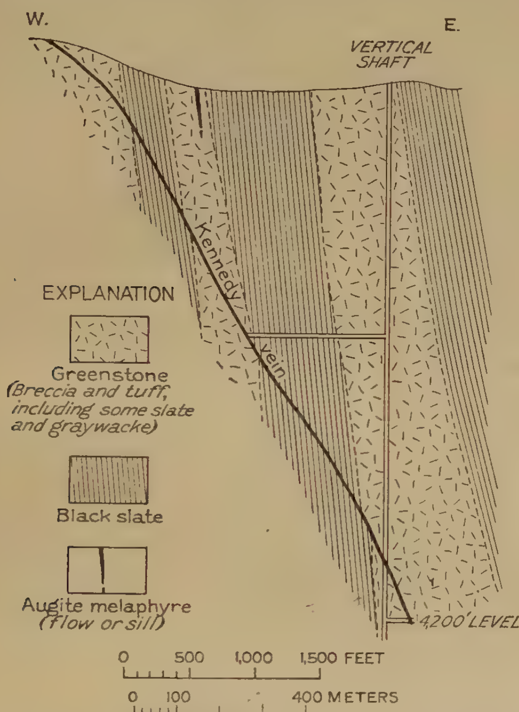

FIGURE 8.—Generalized section through the Kennedy mine along the line of the 1,950-foot crosscut (42, fig. 15)

foot (1,188-meter) level, is described by Hulin (41). Galena was associated with some specimen ore near the south end of the main vein on the 4,200-foot (1,280-meter) level. A fairly large proportion of the vein shows ribbon structure, particularly near the hanging wall. In places this ribboning is cut by veinlets of later quartz. Inclusions of the wall rock in the vein are locally abundant.

Three-quarters of the output is obtained as bullion, and a quarter from concentrate. The concentrates produced during the last decade have averaged 1.25 per cent of the ore milled and carry $110 a ton.

On the 4,500-foot (1,372-meter) level the ore shoot was 700 feet (213 meters) long, having lengthened northward as well as southward, and it had improved in quality. The ore as shown by samples taken during development work ran from $15 to $20 a ton. The samples are as good as any in the previous history of the mine and are highly encouraging as to the downward persistence of ore in the Amador section of the Mother Lode system.

ARGONAUT MINE

The Argonaut mine is 1 mile (1.6 kilometers) north of Jackson and adjoins the Kennedy mine on the south. It is developed by an inclined shaft (fig. 9), which in 1931 had attained a vertical depth of 4,805 feet (1,465 meters). The deepest working in 1931 was the 5,700-foot (1,737-meter) level, as measured on the inclined shaft.

The Argonaut vein, like the Kennedy vein, of which it is the southern continuation, occupies the fissure of a reverse fault and in depth cuts through at an acute angle the same sequence of alternating belts of greenstone and slate.

The outcrop of the Argonaut vein is concealed throughout the greater part of the length of the claim by a capping of Tertiary gravel made up of andesite cobbles. Near the south end line, however, a large cut shows much coarse white quartz, with numerous stringers that branch out from it horizontally or even dip westward. The country rock inclosing this quartz is a deeply weathered schistose greenstone. This quartz outcrop is presumably the top of the Argonaut vein, which here, as at the Kennedy, flattens notably near the surface as the result of refraction on entering the greenstone.

The same succession of slate and greenstone in the hanging-wall country rock as at the Kennedy mine occurs at the Argonaut. In the section through the mine the reverse character of the faulting along the fissure occupied by the vein is well shown. The displacement along the fault fissure occupied by the vein, as measured by the displacement of the slate-greenstone contact in the upper part of the mine, where the dip is relatively flat, is at least 120 feet (37 meters). On the lower levels, where the dip is steeper, the throw is apparently much greater. This difference suggests that there is a strong lateral component in the total displacement.

The country rocks, as at the Kennedy, are composed of greenstone (augite melaphyre tuffs and breccias) and slate, with all

Figure 9.—Section through the Argonaut shaft (42, fig. 18). 1, Tertiary gravel; 2, greenstone; 3, black slate; 4, augite melaphyre (flow or sill); 5, Argonaut vein; 6, gouge veins

the usual intermediate and gradational varieties between them. The finer-textured members have a well-defined foliation or cleavage, and in places the discordance between this foliation and the true bedding planes is as much as 15°.

The wall rocks are hydrothermally altered near the vein. The slates are least affected, but the development of knots of ankerite in them for distances of 5 to 6 feet (1.5 to 1.8 meters) from the vein is characteristic. Much of the greenstone has lost its original appearance almost completely, owing to the wholesale development of ankerite. Where seen on the 2,400, 3,300, and 4,800 foot (732, 1,006, and 1,463 meter) levels this ankeritized rock either forms one of the walls of the vein or is in close proximity to it. Remnants of the original pyroclastic structure may still be seen in much of the material. The rock is similar to the "gray ore" of other Mother Lode mines, and, indeed, it assays as much as $4 a ton here. Although locally called "schist" and considered to be distinct from the greenstone, it is merely a hydrothermally altered facies of that rock.

There are two principal ore shoots—the north shoot, averaging 250 feet (76 meters) in length, and a south shoot, which, on the 4,650-foot (1,417-meter) level, is 160 feet (49 meters) long and in places more than 30 feet (9 meters) wide. The south shoot has a well-defined hanging wall of black slate, along which there is a gouge with its characteristic highly polished black surfaces. The footwall is indefinite, as the vein is underlain by a wide zone of stringers, which was said to assay $8 a ton over a width of 24 feet (7.3 meters). The shoot bulges from a few feet to its maximum width within a short distance. This south shoot was a comparatively recent discovery. The north shoot, as seen just below the 4,200-foot (1,280-meter) level, differs from the south shoot in that it has a thick gouge on both footwall and hanging wall.

From the surface down to the 2,530-foot (771-meter) level there was but one shoot of ore, which lay north of the shaft and had practically no rake. This shoot has a maximum length of 600 feet (183 meters) and an average length of 300 feet (91 meters). It was a continuation of the main Kennedy shoot and had essentially the same zones of lower-grade ore as were found in that mine. Below the 2,530-foot (771-meter) level the shoot raked 30° S. and terminated on the 3,300-foot (1,006-meter) level. Below the 3,300-foot level a new shoot came in some distance north of this point and directly under (on the dip) the upper part of the old shoot. The ore on these lower levels, particularly that of the south shoot, was of as good grade as any previously extracted.

The quartz in the south shoot was coarse, massive, homogeneous, and without noticeable sulphides. In appearance it resembled numerous barren veins, yet 5-foot (1.5-meter) samples assayed as high as $80 a ton. Free gold is not uncommon. The ore of the north shoot, however, is like that of other Mother Lode mines, being broadly banded by inclusions of black slate that are parallel to the hanging wall. Like the south shoot it also had a notably small content of sulphides.

On the 4,800-foot (1,463-meter) level the ore shoot was 950 feet (290 meters) long and attained a maximum width of 60 feet (18 meters), and the ore was of good grade.

CENTRAL EUREKA MINE

The Central Eureka mine is 2 miles (3.2 kilometers) north of Jackson, on the north edge of the broad upland between that town and Sutter Creek. It is developed by a three-compartment shaft (fig. 10) inclined 70° E. The bottom level in 1928 was the 4,800-foot (1,463-meter), about 4,380 feet (1,335 meters) vertically below the collar. The output to the end of 1930 was about $10,000,000. During 1930 the average assay value of the ore milled was $6.90 a ton, of which $6.12 was extracted.

The geologic section across the strike in the line through the shaft comprises, from west to east, (1) amygdaloidal basalt carrying prominent crystals of augite in a dark groundmass, apparently a fresh rock; (2) slate, 40 feet (12 meters) thick; (3) schistose greenstone tuff and breccia, 150 feet (46 meters) thick; (4) black slate, 400 feet (122 meters) thick; (5) augitic basalts and tuffs (greenstone). All these dip 80° E. At the surface the fifth belt is covered by a gravel of andesite boulders, a remnant of a Tertiary intervolcanic stream deposit.

The shaft is sunk under the hanging wall of the Hanging Wall vein as far as the 2,000-foot (610-meter) level, where it passes into the footwall country rock. As shown in Figure 10, the vein in the upper levels was inclosed in slate, but at a depth of 1,000 feet (305 meters) the hanging wall became greenstone, and at 1,100 feet (335 meters) the bonanza shoot came in, which extended down to the 1,900-foot (579-meter) level with northerly pitch. The maximum stope length of this shoot was 700 feet (213 meters). Much of the ore averaged $70 a ton.

Below the 1,900-foot (579-meter) level the Hanging Wall vein became lean, and on the 3,100-foot (945-meter) level it was barren. It had flattened from an average dip of 70° E. to 50° or less on the 3,100-foot level, below which it has not been prospected. On the 2,800-foot (853-meter) and other levels down to the 3,350-foot (1,021-meter) level was cut the West vein, a gouge-filled fissure dipping 70° E. and carrying but a trace of

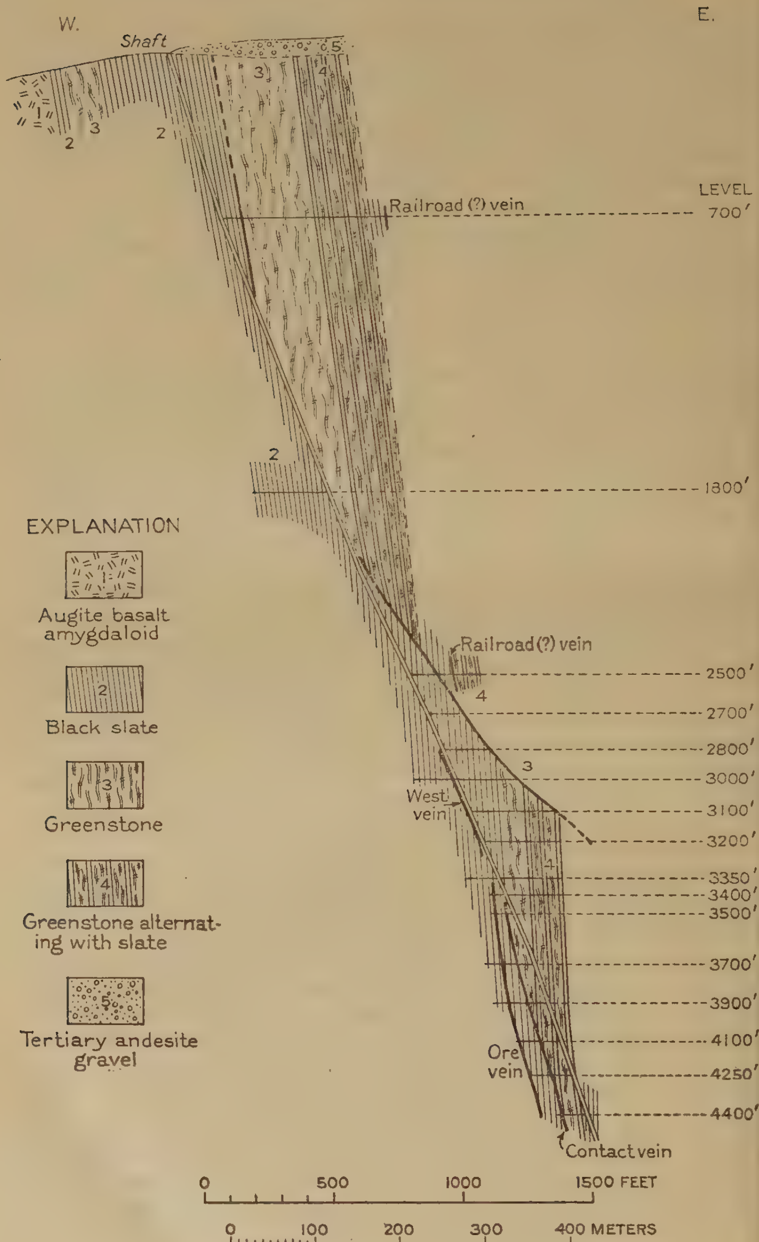

FIGURE 10.—Section through the Central Eureka shaft (42, fig. 13)

gold. The black slates lying between the Hanging Wall vein and the West vein are much disturbed and locally dip west, in places as low as 50°. The slates under the West vein, as shown by the 175-foot (53-meter) crosscut in its footwall on the 3,000-foot (914-meter) level, are very regular. In the belt between the two veins occurred a number of the so-called intermediate veins or ore bodies. They supplied the bulk of the ore mined in 1915. The intermediate ore body on the 3,000-foot level, for example, was 330 feet (100 meters) long, ranged from 4 to 10 feet (1.2 to 3 meters) in thickness, and averaged $5 a ton. It stood nearly vertical, its walls were irregular, the adjacent slate was gashed with horizontal veinlets of vuggy quartz 1 to 2 inches (2.5 to 5 centimeters) thick, and as is characteristic of all such intermediate veins, there was no gouge.

The ore shoot of the deeper levels was first found on the 3,500-foot (1,067-meter) level. The geologic relations exposed here have persisted with remarkable regularity to the greatest depth attained. The shoot persisted up to the 3,400-foot (1,036-meter) level, and the relation of the vein to the veins of the higher levels is lost in caved ground.

The vein containing this ore shoot, which may be called the Ore vein, is 32 feet (9.7 meters) west of what is called the Contact vein. On the deeper levels the interval between the two veins is as much as 70 feet (21 meters), and the rock between them is highly disturbed black slate. The Contact vein is a well-defined fissure, mostly filled with gouge and carrying in places $1 or $2 to the ton. Its hanging-wall rock is greenstone alternating with slate, including tuffs or graywackes speckled with quartz particles.

The ore shoot where first cut on the 3,500-foot (1,067-meter) level was only 60 feet (18 meters) long but contained high-grade ore, in places assaying $50 a ton in 6-foot (1.8 meter) samples. The relations on the 4,250-foot (1,295-meter) level are typical. The vein cuts the strike of the strata at an acute angle. The main ore body consisted of a lens of highly ribboned quartz, in which the ribbons were wavy or corrugated. It assayed about $20 a ton, though carrying little sulphide and that chiefly pyrite. The lens was 180 feet (55 meters) long, and its maximum width was 35 feet (10.7 meters); it dipped 75° E. and pitched steeply northward. There were thick gouges on both walls, and the intervening quartz was much fractured and largely crushed to a sugary condition. The hanging-wall rock is black slate, greatly crumpled, and the footwall at the south end is black slate inclosing a 3-foot (0.9-meter) layer of greenstone; at the north end of the shoot the footwall rocks are banded black

and green slates. At the south end of the ore shoot the quartz pinches out abruptly, but the gouge continues; in places the fissure is filled with 8 feet (2.4 meters) of shiny black gouge without quartz.

Black slates without interlayered greenstones form the footwall country rocks on the upper levels, as uniformly shown by the crosscuts; in fact, on the 1,800-foot (549-meter) level a belt at least 300 feet (91 meters) thick has been crosscut. On the lower levels, however, greenstone is beginning to appear, for in the south footwall crosscut on the 3,700-foot (1,128-meter) level at least 200 feet (61 meters) of greenstone is shown.

EUREKA MINE

In 1924 the Eureka mine, which adjoins the Central Eureka on the north, was bought by the Central Eureka Mining Co. It is one of the most famous of Mother Lode mines; and after having attained a depth of 2,063 feet (629 meters) on the incline and produced $12,000,000 it was shut down in 1886.

In recent years the Eureka property has been energetically explored by its new owners, and valuable ore bodies have been found. In fact, it now furnishes the main supply of ore for the company. It is worked through a long underground connection with the Central Eureka.

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TERTIARY AURIFEROUS GRAVEL

By Adolph Knopf

Deposits of auriferous gravel occur as more or less connected remnants on the summits of the ridges between the canyons of the western slope of the Sierra Nevada. The oldest of these deposits, called the white gravels because of the prevalence of white quartz and siliceous rocks in them, were laid down in the streams of a westward-flowing drainage system of middle Eocene age. Later, probably early in the Miocene, these gravels were buried under rhyolite tuffs, and still later, in upper Miocene or lower Pliocene time, they were covered by immense eruptions of andesitic tuff and breccia, which converted the Sierra region into

a volcanic plain. The gravel deposits that accumulated during the period of the eruptions are known as the intervolcanic gravels. They consist chiefly or wholly of volcanic detritus and as a rule are barren of gold, except locally where the intervolcanic streams eroded through the white gravels and robbed them of their gold.

The Tertiary auriferous gravels are estimated to have yielded $300,000,000, almost all of which came from the white gravels. They were worked until 1884 by hydraulic mining, or where the volcanic overburden was too thick the paystreak on bedrock was extracted by tunneling operations in the so-called drift mines. The placer miners accomplished work of geologic magnitude. Before being stopped by adverse legislation they had moved eight times as much material as was excavated in digging the Panama Canal.

The gravel tailings dumped into the streams by hydraulic mining decreased the navigability of the streams in the Great Valley of California and increased the height of the spring floods. For these reasons hydraulic mining was halted by court injunction in 1884, and such severe legal restrictions were placed on the industry that it was all but completely stopped. According to a recent estimate there is still locked up in the gravels $600,000,000, which it is thought could be extracted were hydraulic mining again feasible.

The former great richness of the Quaternary gravels, from which $900,000,000 has been taken, was the result of tapping the stores of gold in the Tertiary auriferous gravels and their concentration in the present streams, and to this already generous supply was added the gold released from the quartz veins and veinlets during the excavation of the great canyons.

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ITINERARY, YOSEMITE TO MOTHER LODE

By Walter W. Bradley

[Note.—For trip from Glacier Point to floor of Yosemite Valley and out by way of north rim as far as Carl Inn, see itinerary for Yosemite Valley, pp. 73–81]

YOSEMITE VALLEY TO SONORA

22.4 (36).[6] Carl Inn Road branches to east (right) for Tioga Pass. This is still within the area of the granodiorite batholith.

28.6 (46). Old placer-gold diggings.

34–35.5 (54.7–57.1). At the Cliff House and for 1½ miles (2.4 kilometers) beyond, the contact between the granodiorite and the Calaveras formation is crossed and recrossed. The Calaveras consists of argillite, limestone, quartzite, and mica schist and contains gold-bearing quartz veins here and there. The road here for 16 miles (25.7 kilometers) passes through a belt of Calaveras, except that at 46 miles (74 kilometers) and at Big Oak Flat isolated areas of quartz diorite are crossed. The gold mines in the vicinity of Groveland and Big Oak Flat are in what is known as the "east belt," being 6 to 10 miles (9.6 to 16 kilometers) east of and roughly parallel to the Mother Lode gold belt. At about 48 miles (77 kilometers) the road passes under Hangman's Tree, and to the left stands Bret Harte's cabin.

51.5 (82.9). Priest's station. At this point amphibolite schist, derived from andesitic tuff and breccia, diorite, and other igneous rocks, is met; and the road going down grade for 6½ miles (10 kilometers) to Moccasin Creek crosses and recrosses the contact between the Calaveras schists and the amphibolite. A narrow belt of serpentine and a soda syenite dike, traceable for more than 10 miles (16 kilometers) north and south are also crossed. For a part of the distance this dike separates a belt of Mariposa slate on the west from Calaveras schist on the east.

55 (88.5). To the left is seen the Moccasin Creek power house (hydroelectric) of the city of San Francisco. This is a unit in the Hetch Hetchy water-supply system.

58 (93). Cross Moccasin Creek.

58.3 (93.8). Cross the Tuolumne River.

58.8 (94.6). Harriman mine, on the Mother Lode gold belt.

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[6] Figures indicate distance from Yosemite village in miles, with kilometers in parentheses.

60.5 (97.4). Jacksonville, on Woods Creek, on Mariposa slate. There is also at this point a small area of auriferous gravel. After leaving Jacksonville, the highway successively passes through belts of meta-andesite, serpentine, and metadiabase; and at Chinese Camp another and larger area of auriferous gravel.

61.7 (99.3). Eagle-Shawmut mine, across Woods Creek to right. This mine for many years was one of the largest gold producers of the southern section of the Mother Lode. It is credited with a total yield of over $5,000,000.

64.5 (103.8). Table Mountain lava flow can be seen ahead.

65 (104.6). Chinese Camp.

65.3 (105.) Turn right on short-cut road to Sonora highway.

68.5 (110.2). Montezuma. A large area (about 2 miles (3.2 kilometers) long by half a mile (0.8 kilometer) wide) of auriferous river gravel.

68.6 (110.4). Oakdale-Sonora highway. Turn right. From this point the road successively passes over Mariposa slate, metadiorite, serpentine, and meta-andesite.

70.6 (113.6). Mother Lode, white quartz outcrops. Mark Twain-Bret Harte Trail Marker, for Woods Creek Crossing. First gold in this district found at a point 500 feet (152 meters) southeast.

70.8 (113.9). Harvard mine, formerly a large producer. This mine has three veins, averaging 10 feet (3 meters) in width; footwall serpentine, hanging wall Calaveras slate. The shaft is 1,850 feet (564 meters) deep. The total reported output has been $2,500,000.

71.7 (115.4). Jamestown. Calaveras schist. On leaving the town the highway crosses onto amphibolite schist, which continues to the outskirts of Sonora, where the Calaveras is again seen.

74.8 (120.4). Sonora. Some rich pocket mines have been worked here, notably the Bonanza. This area, which is east of the Mother Lode, is characterized by a belt of limestone lenses in the Calaveras formation.

SONORA TO SACRAMENTO

78 (125.5). Old Columbia placer diggings. Marble bedrock, deeply fissured and potholed. Was very rich, and gold was high grade, as much as 0.950 fine. Records of Wells, Fargo & Co. show $55,000,000 worth of nuggets and gold dust shipped through their express office. District credited with total yield of $87,000,000 gold.

80 (128.7). Columbia. In 1853 had 18,000 population and came within two votes of being chosen capital of the State. Return westward toward Mother Lode.

82.8 (133.3). Table Mountain lava cap at left; from this flow came the type material of latite, as defined by Ransome.

84.5 (136). Amphibolite schist.

85.2 (137.1). Tuttletown, on Mother Lode. On Jackass Hill, 1 mile (1.6 kilometers) north of the town, is the cabin in which Mark Twain lived during the sixties of the last century and wrote some of his famous stories.

88.3 (142.1). Stanislaus River. The highway bridge marks the location of old Robinson's Ferry. The river marks the boundary between Tuolumne and Calaveras Counties. The Melones and Carson Hill mines are here, on the Calaveras (north) side of the river. Both have been notable producers. In the Morgan claim of the Carson Hill group, on the north side of Carson Hill, was taken out the famous $300,000 pocket in which was included a single mass of gold weighing 2,340 ounces (72,782 grams) and valued at $43,534. These mines are in a belt of thoroughly metamorphosed rocks, chiefly of pyroclastic origin, but including some interbedded sediments of Calaveras age and some basic intrusive rocks.

90.8 (146.1). As the road rounds the north side of Carson Hill a prominent white outcrop of bull quartz can be seen ahead on Chaparral Hill, across the canyon to the north.

91.8 (147.7). Irvine (town of Carson Hill); Morgan mine at right.

94.4 (151.9). Mother Lode outcrop at left. The lode splits at this point and through Angels Camp.

95.1 (153). At right, mill crushing and screening "greenstone" (amphibolite) for use in roofing and stucco dash. At left, mill of Gold Cliff mine, on west spur of Mother Lode; an excellent exposure visible in the open cut.

95.9 (154.3). Angels Camp. The Utica group here, on the Mother Lode east spur, produced $14,000,000 to a depth of 3,200 feet (975 meters), the bulk of which came from above the 1,000-foot (305-meter) level. The Lightner, Angels, and Sultana mines here were also active producers for many years.

102.8 (165.4). Fourth Crossing.

107.1 (172.4). Old placer diggings at right; Tertiary auriferous gravel. Two miles (3.2 kilometers) to the west is the plant of the Calaveras Portland Cement Co., utilizing limestone from lenses in the Calaveras formation.

108.2 (174.1). San Andreas.

112.6 (181.2). Highway turns to right (eastward) from Mother Lode. From this point to Mokelumne (mo-kel′um-ne) Hill (about 4½ miles, or 7.2 kilometers) is a series of Tertiary auriferous gravels, mainly to the right of the highway, in part overlain by andesite tuff and breccia.

117 (188.3). Mokelumne Hill. From this place to a point about a mile (1.6 kilometers) north of the river is an area of metadiorite.

120.5 (193.9). Mokelumne River. This stream is an important source of hydroelectric power, the Pacific Gas & Electric Co. having plants above this crossing. It is also the main source for the water system of the East Bay Municipal Utility District, which supplies the cities of Oakland, Berkeley, Alameda, and Richmond. The river is the boundary line between Calaveras and Amador Counties.

121.2 (195). Calaveras schist.

122 (196.3). Site of old Butte City placer diggings. Gravel seen under a capping of rhyolite tuff, west of which is a belt of amphibolite schist.

123.7 (199). Moore mine (at left), on Mother Lode.

125.5 (202). Jackson, county seat of Amador County.

125.9 (202.6). Argonaut mine. The shaft and mill are above on the ridge at the left.

126.2 (203.1). Highway crosses outcrop of Mother Lode. Turn right to Kennedy mine, the vertical shaft of which is in the hanging-wall (east) side of the lode.

127.2 (204.7). Kennedy mine. The Argonaut and Kennedy mines, both of which are practically a mile (1.6 kilometers) deep, vertically, are to-day the deepest gold mines in North America.

127.9 (205.8). Cap of andesite gravel, a remnant of a Tertiary intervolcanic river deposit, at right. Summit House.

128.4 (206.6). Central Eureka mine; South Eureka at right. For several years the Central Eureka was one of the three largest gold producers on the Mother Lode belt.

128.9 (207.4). Old Eureka mine, now operated by Central Eureka Co.

129.2 (207.9). Sutter Creek.

131.7 (211.9). Amador City. Keystone mine at right, a former large producer. The Mother Lode here is in Mariposa slate and associated greenstone.

132.2 (212.7). Highway turns left (west) from the Mother Lode, and traverses a belt of meta-andesite.

134.7 (216.8). Drytown. On the west is the contact between the meta-andesite and the Calaveras formation.

135.8 (218.6). Junction of Mother Lode highway with road from west (Sacramento Valley). Plymouth mine is 2 miles (3.2 kilometers) north. Turning westward the road crosses successively the Calaveras formation, meta-andesite, serpentine, and amphibolite, and for several miles through a series of bench and shore gravels which are auriferous and which were mined in part by hydraulicking; and finally the Quaternary valley alluvium deposits of clay, sand, loam, and gravel.

146.6 (236). Michigan Flat placer diggings.

148.8 (239.5). Cosumnes (co-sum′nees) River. Note lava flow beneath bench gravel.

165.9 (266.9). Perkins. Turn right (east) onto Placerville highway.

171.9 (276.6). At right, Mather Field, U. S. Army Air Service post.

174.8 (281.3). Tailings piles of gravel from operation of gold dredges.

175.2 (281.9). Salsbury station. Turn right across railroad to gold dredges of Natomas Co. Return west on highway. The Folsom dredge field, at the mouth of the canyon of the American River, now mostly exhausted, was the largest in the State, comprising 13,000 acres (5,260 hectares) of Quaternary gravel. It extends mainly along the south side of the river for 7 miles (11.2 kilometers) and is 1 to 2 miles (1.6 to 3.2 kilometers) wide. The gravel is 19 to 70 feet (5.8 to 21 meters) thick and rests on a so-called false bedrock of andesite tuff. The gold occurs as minute flat flakes; and the gravel ranges in value from 6 to 18 cents a cubic yard, averaging about 10 cents.

190 (305.8). Sacramento, at the junction of the American and Sacramento Rivers, in the Great Valley of California, 20 feet (6 meters) above sea level. At low-water stages there is a 2-foot (0.6-meter) tidal effect in the river here, from the Pacific Ocean, approximately 100 miles (161 kilometers) distant.

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were mined in part by hydraulicking;
Quaternary valley alluvium deposits of
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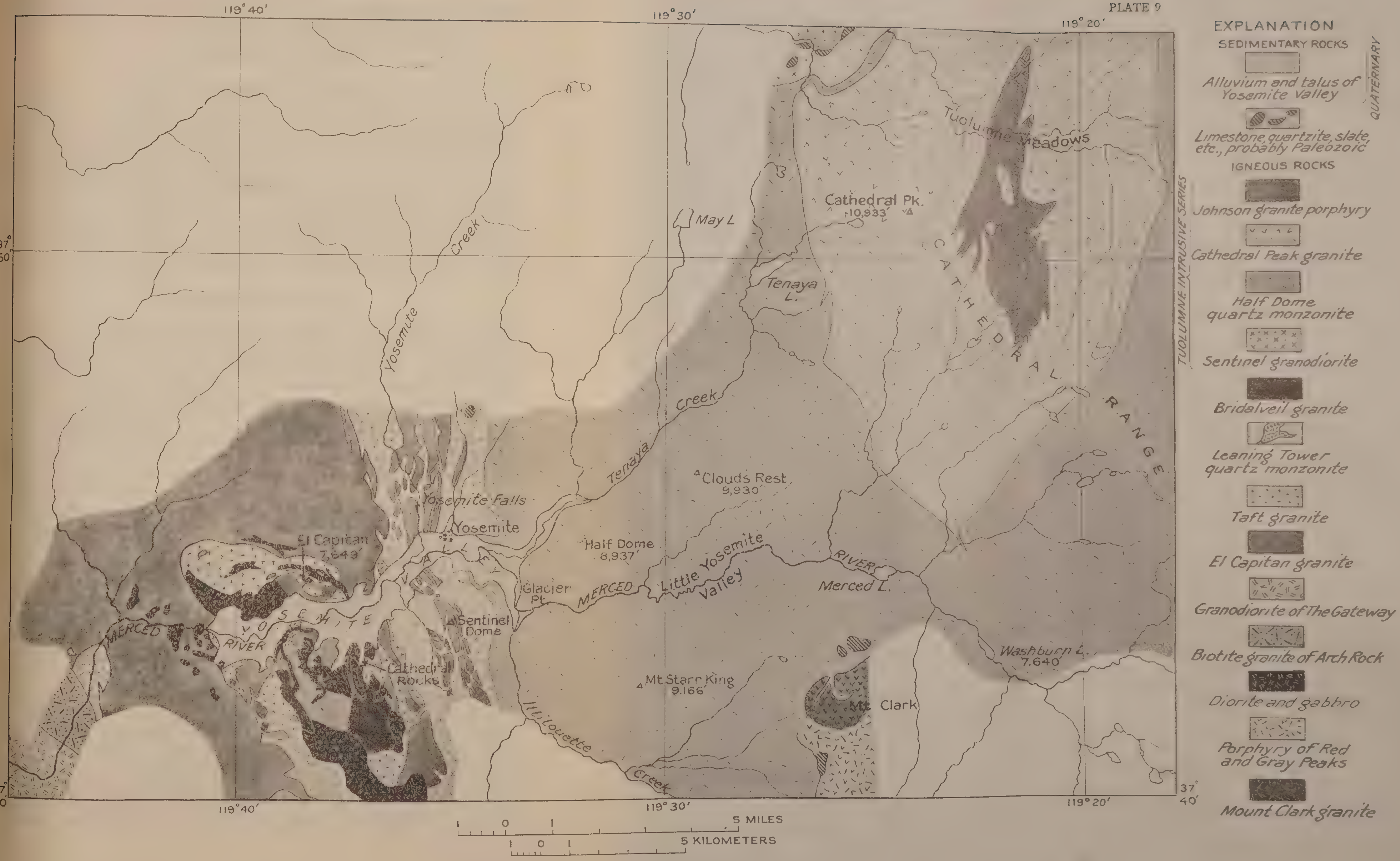
meters) distant.



GEOLOGIC MAP OF YOSEMITE REGION

After U. S. Geol. Survey Prof. Paper 160, pl. 51, 1930.

UP THE WESTERN SLOPE OF THE SIERRA NEVADA BY WAY OF THE YOSEMITE VALLEY

By François E. Matthes

SCOPE AND PURPOSE OF EXCURSION

This excursion is designed to afford a geologic cross section of the central part of the Sierra Nevada, of which the Yosemite Valley is the principal feature, and an insight into its morphologic development and glacial history.

From Merced, at the foothills, the route leads up the lower slope of the range to Wawona and the Mariposa Grove of Big-trees, thence through the Yosemite region, on the middle slope, and the High Sierra, on the upper slope, to Tioga Pass, on the crest line, where the descent of the eastern escarpment begins. (See pl. 8.)

GEOGRAPHIC SKETCH

The western slope of the Sierra Nevada, in the latitude of the Yosemite region, rises from an altitude of 250 feet (76 meters) at the foothills to more than 13,000 feet (3,962 meters) at the crest line, but this rise is made in a distance of 67 miles (108 kilometers), and as a consequence the mean angle of inclination is only slightly more than 2°. So rugged, however, is the surface in detail that to one traveling among its gulches and ridges the unity and gentle inclination of the slope are not manifest, the effect being rather that of a chaotic mountain region whose features have no apparent system.

This chaotic aspect prevails especially on the lower part of the slope, where the courses of the lesser streams are in large part adjusted to the northwestward-trending structure of the metamorphic rocks and where even the master streams deviate widely from southwesterly courses, directly down the slope. The middle part has a simpler, more massive type of topography, developed on the granitic rocks of the batholith. It is a region of billowy uplands gashed at intervals of about a dozen miles (20 kilometers) by deep canyons. Two of these canyons, those of the Merced and Tuolumne Rivers, are of especial interest. The canyon of the Merced, narrow and V-shaped throughout its lower course, widens abruptly at a distance of 60 miles (96 kilometers) from the foothills to the broad-floored, sheer-walled Yosemite Valley. This valley is about 7 miles (11 kilometers) long, lies at an altitude of 4,000 feet (1,219 meters) above the sea, and has walls ranging from 3,000 to 4,000 feet (914 to 1,219 meters) in height. The canyon of the Tuolumne River, to the north, similarly widens out into the Hetch Hetchy Valley, which

is analogous to the Yosemite in general character but only half as long. Both valleys owe their distinctive character not only to their sharply walled-in forms but to the prevailingly massive sculpture of their cliffs and to the presence of great domes of bare granite on their brinks and of high waterfalls of the Staubbach type that leap from the mouths of hanging valleys.

The High Sierra is less deeply trenched than the middle slope but is surmounted by serrate crests that stand 2,000 to 3,000 feet (610 to 914 meters) high and that give it a distinctly alpine character. These are the Clark Range, immediately above the Yosemite; the Cathedral Range, which divides the headwaters of the Merced from those of the Tuolumne; and the main crest of the Sierra Nevada, which bears the highest peaks—Mount Lyell (13,090 feet, or 3,989 meters) and Mount Dana (13,050 feet, or 3,977 meters).

The Yosemite region and that part of the High Sierra which adjoins it constitute together one of the most scenic mountain areas in the Sierra Nevada and therefore are appropriately embraced in the Yosemite National Park. In the lower portion of this reservation are also majestic forests, including three groves of *Sequoia gigantea*—the Mariposa grove, at the southern border, and the Merced and Tuolumne groves, at the western border. The High Sierra lies largely above timber line and in the Alpine zone. All its higher peaks and crests stand bare; many of them are flecked with snow fields throughout the summer; a few even bear small glaciers.

The Yosemite Valley, which is the central feature of the park, was first sighted by a white man in 1833—Joseph Reddeford Walker, who, on his way across the Sierra Nevada with Indian guides, passed over the uplands to the north of the chasm. But the valley did not really become known to the world until the spring of 1851, when the historic Mariposa Battalion of miners and frontiersmen, sent out to punish the marauding Yosemite Indians, unexpectedly came upon the natural stronghold of the tribe. The name Yosemite, which is a euphonic approximation to the almost unpronounceable name of the Indians (said to mean grizzly bear), was bestowed upon the valley by Dr. Lafayette H. Bunnell, who accompanied the expedition.

GEOLOGY

A section across the Sierra Nevada drawn approximately along the route of the excursion up the western slope is essentially like that shown in Figure 3. The lower part of the slope is composed of metamorphic rocks, the middle and upper parts almost wholly of granitic rocks, the crest and the eastern escarpment of metamorphic rocks.

The route crosses the lower belt of metamorphic rocks near its southeastern extremity, where the gold-quartz veins of the Mother Lode system die out. The rocks here consist largely—from the foothills to the vicinity of Mariposa—of the Mariposa slate, of Upper Jurassic age. Only a narrow zone adjacent to the batholith consists of the Calaveras formation, which is of Carboniferous age. The strata of both formations are compressed in parallel, almost isoclinal folds with northwestward-trending axes and steep northeasterly dip.

The Calaveras formation consists mainly of quartzite and phyllite, with a few lenses of marble, thin beds of radiolarian chert, and intercalated masses of volcanic rocks. The Mariposa formation consists chiefly of carbonaceous slate with lenses of limestone and large masses of greenstone of volcanic origin. Small isolated bodies of metamorphic rocks, composed mostly of quartzite and schist, are widely scattered throughout the area of the batholith, notably on the slope east of Sentinel Dome, on the northern spur of Mount Clark, and on the west side of Tuolumne Peak. White marble occurs at the southeast base of Mount Hoffmann and in the basin on the north side of that peak. The metamorphic rocks on the crest of the range are chiefly quartzites and argillites of many different hues, but there are also bodies of metamorphosed pyroclastic rocks—for instance, on the upper slopes of Mount Dana. The age of these metamorphic rocks is still undetermined.

The intrusive rocks composing the batholith range all the way from nearly black gabbro through diorite, granodiorite, quartz monzonite, and biotite granite to nearly white alaskite. The acidic rocks predominate and occur in the largest intrusive masses. Of outstanding interest in connection with the development of the Yosemite Valley is the fact that, whereas the greater part of the batholith is made up of intrusions 100 square miles (259 square kilometers) or more in extent, there is a complex of small, intricately related intrusions in the valley area, and many of these small intrusions are composed of basic rocks.

At least two sequences of intrusion have been recognized by Calkins (22)[7] and by Cloos (10). According to Calkins the most clearly defined is the sequence which consists, in order of succession, of Sentinel granodiorite, Half Dome quartz monzonite, Cathedral Peak granite, and Johnson granite porphyry. (See pl. 9.) Each of these intrusives is more siliceous than its predecessor, and they are arranged concentrically about one another in a dome-shaped mass, with the youngest and most siliceous at the center.

[7] Numbers in parentheses refer to bibliography, p. 39.

GEOMORPHOLOGY

The region traversed by the excursion exhibits geomorphic features representative of each of the four main cycles of erosion outlined in the section on the geography and geology of the Sierra Nevada (pp. 26–40)—namely, the early Eocene, Miocene, Pliocene, and Pleistocene. The lower slope, naturally, is richest in Pleistocene features. The ramifying gulches that dissect it are mostly of Pleistocene age. The intricacy of the drainage pattern is due to the fact that many of the stream courses are adjusted to northwestward-striking belts of weak rocks in the Mariposa and Calaveras formations. Even the master streams reflect in their wide deviations from a direct down-slope course the influence of the transverse structure.

The undulating uplands of the middle slope bear large tracts of the Pliocene and Miocene surfaces. These older surfaces remain preserved owing to the resistant nature of the prevailingly massive granitic rocks. The uplands flanking the Yosemite Valley are typical examples of the Miocene surface. (See pl. 6, *B*.)

The great depth of the Yosemite Valley is accounted for by the fact that the chasm is the product of three successive cycles of stream cutting—the Miocene, Pliocene, and Pleistocene—and of glacial erosion in addition. Prior to glaciation it was a 3-story canyon, as shown in Figure 11, *a*. As a result of the great enlargement of its cross section by glacial action its walls now rise directly from its floor to the Miocene hills on the uplands. (See fig. 11.)

The three cycles of stream cutting are indicated by three sets of hanging side valleys differing greatly in altitude. The upper set is representative of the Miocene cycle, the middle set of the Pliocene cycle, and the lower set of the Pleistocene cycle. Only the valleys of the lower set hang in consequence of the glacial deepening and widening of the main valley. (See fig. 12.) The valleys of the two higher sets were left hanging long before the glaciers came, in consequence of the inability of their streamlets to trench the granitic rocks as rapidly as the master stream, after each of the two great uplifts of the Sierra block that came at the end of the Miocene epoch and the beginning of the Pleistocene epoch. (See pp. 35–36.)

The High Sierra above the Yosemite region has not yet been penetrated by the gorges of the Pleistocene cycle. Its main valleys all belong to the Pliocene cycle. The Little Yosemite and the broad upper valley of the Tuolumne River, through which the route of the excursion leads, are typical examples of Pliocene valleys, remodeled by glacial action. The benches that flank these broad valleys and the hanging side valleys

associated with the benches represent the Miocene cycle. The lofty peaks and mountain ranges that stand above the benches—Mount Hoffmann, the Clark Range, the Cathedral Range, Kuna Crest, and the main crest of the Sierra Nevada—are pre-Miocene. The tabular tops on some of the peaks, notably on Mount Dana and Parsons Peak, are remnants of the early Eocene surface.

a

b

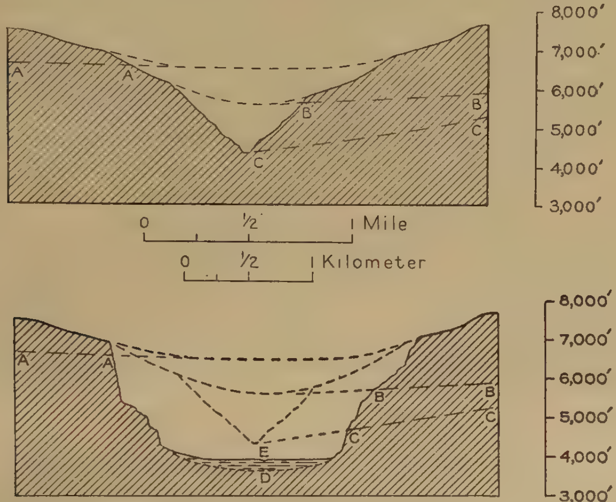


FIGURE 11.—*a*, Generalized cross profile of Yosemite Valley before glaciation The broad, shallow valley at the top was produced during the Miocene cycle the deeper valley below during the Pliocene cycle, and the V-shaped gorge at the bottom during the early part of the Pleistocene. Side valleys (A–A and B–B) were left hanging with each rejuvenation of the master stream, but a few tributaries, such as C–C, flowing over relatively unresistant rocks, were able to cut their gulches down to the bottom of the main canyon. *b*, Generalized cross profile of Yosemite Valley after glaciation. The rock floor of the glacial trough is at D. The present valley floor E is on alluvium filling a glacially excavated lake basin. The gulch C–C now also "hangs," and thus there are three sets of hanging side valleys, at different elevations one above another, all having waterfalls pouring from their mouths. Vertical scale equals horizontal scale

GLACIATION

From a detailed survey of the moraines in the Yosemite region it is evident that the Yosemite Valley was invaded by a trunk glacier at least three and probably four separate times during the Pleistocene epoch. The stages of glaciation definitely recognized are, in chronologic order, the Glacier Point, the El Portal, and the Wisconsin (Würm). The Wisconsin had two maxima.

The Yosemite Glacier was formed each time by two confluent glaciers of nearly equal strength that came from the High Sierra—the Merced Glacier, which occupied the upper Merced Canyon, and the Tenaya Glacier, which occupied Tenaya Canyon but was fed mainly by ice diverted from the Tuolumne Basin. At the time of its maximum extension—during the El Portal stage (presumably the correlative of the Illinoian, or Riss)—the Yosemite Glacier penetrated the Merced Canyon below the Yosemite Valley for a distance of 10 miles (16 kilometers), ending near the site of El Portal. During the Wisconsin stage it reached no farther than the Bridalveil Meadow, in the Yosemite Valley. It is evident from these facts that the bulk of glacial erosion in the valley was accomplished during the earlier stages.

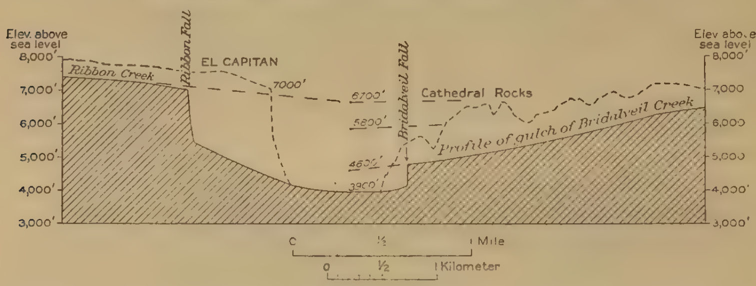


FIGURE 12.—Cross profile of Yosemite Valley showing hanging valleys of Ribbon Creek and lower Bridalveil Creek (22, fig. 12). The depth of the Yosemite Valley at the end of the Miocene cycle is indicated by the projected profile of Ribbon Creek. Its preglacial depth is indicated by the profile of Bridalveil Creek. The intermediate figure, obtained from other hanging valleys, indicates the depth during the Pliocene cycle

Glacial erosion was effectively controlled by the structure of the granitic rocks. In the areas of well-developed jointing immense quantities of rock were quarried out block by block; but in the areas of massive granite, where the quarrying process was not operative, only slight changes were wrought by abrasion. The capacious U form of the Yosemite Valley is largely a product of glacial quarrying. It attains the greatest width, notably, in the areas where small intrusions of diorite and gabbro predominate, these rocks being the most closely jointed; the only constriction, the portal between El Capitan and the Cathedral Rocks (pl. 10), is between opposing bodies of massive granite. The narrowness of the gorges immediately above and below the Yosemite Valley is due to the massive habit of the siliceous granites that make up those parts of the batholith. In spite of vigorous glaciation these gorges differ but little in aspect from purely stream-worn gorges.

The depth of glacial excavation in the Yosemite Valley increases from 500 feet (152 meters) at its lower end to 1,500 feet (457 meters) near its head. The great depth of excavation and the correspondingly radical change in configuration at the valley head are attributed in large part to the powerful excavating action of an ice cataract that plunged from the platform at the base of Half Dome during the times of maximum glaciation, when the Merced and Tenaya Glaciers coalesced over the divide between their paths.

ITINERARY

Merced (altitude 170 feet, or 52 meters).—The town of Merced is situated a few miles from the foothills of the Sierra Nevada. It is the center of a thriving farming and fruit-growing district, which depends for irrigation largely upon water diverted from the Merced River, to the north.

Foothills and lower slope.—From Merced the route leads for the first 15 miles (24 kilometers) directly eastward over the almost level alluvial floor of the Great Valley. It then enters the foothills of the Sierra Nevada and winds up through the ramifying valleys and gulches that dissect the lower slope, maintaining a northeasterly course toward Mariposa. The rocks consist mostly of the Upper Jurassic Mariposa slate. Slabs of slate stand out here and there like gravestones on the otherwise smooth slopes of the hills. The Mariposa slates have in consequence become known locally as the "gravestone slates."

The dissection of the lower slope is due mainly to the Pleistocene cycle of erosion. So chaotic is the intaglio of small forms that it is difficult to distinguish any features left from earlier cycles. One feature of that kind, however, stands out prominently in the landscape—the Guadalupe Mountains (altitude 2,868 feet, or 874 meters), around the south and east sides of which the road passes. They are a typical example of a northwestward-trending ridge that bears on its summits small remnants of an early Tertiary surface of erosion.

East of the Guadalupe Mountains, just beyond Agua Fria Creek, the road leaves the metamorphic rocks and enters the vast area of granitic rocks of the Sierra batholith. It also enters the historic Spanish land grant of Las Mariposas (the butterflies), in which the Mother Lode system has its southern terminus and in which the first gold-quartz vein was discovered in 1849. The veins lie mostly to the southwest of the town of Mariposa, in a belt of Jurassic rocks. They die out in the granite near by.

From the vicinity of Mariposa the road runs in an easterly direction over granitic rocks divided here and there by narrow belts of metamorphic rocks of the Calaveras formation. Near

Miami it turns northeastward and leads up over the Chowchilla Mountains (altitude 7,079 feet, or 2,158 meters), another high northwestward-trending ridge bearing a remnant of the Miocene surface, and then it descends toward Wawona. Before reaching Wawona, however, a side trip is made southeastward to the Mariposa Grove of Bigtrees.

Mariposa Grove of Bigtrees.—The Mariposa Grove is in the southernmost part of the Yosemite National Park. It is typical of the numerous groves of *Sequoia gigantea* that stand, interspersed with other trees, in the great forest belt of the Sierra Nevada. About 200 of the sequoias in the grove measure more than 10 feet (3 meters) in diameter at a height of 10 feet (3 meters) above the ground; eleven of the trees measure 16 feet (4.9 meters) or more in diameter; three measure 20 feet (6 meters) or more. All the mature trees reach a height of 200 feet (61 meters); two exceed 300 feet (91 meters). The Grizzly Giant is believed to be the oldest tree in the grove. It is 204 feet (62 meters) high and measures 20.5 feet (6.25 meters) in diameter. Its age is estimated at somewhat less than 4,000 years.

The Mariposa Grove stands on the west spur of Raymond Mountain at altitudes ranging from 5,500 to 7,000 feet (1,676 to 2,134 meters). This spur is unglaciated, but the valley of the South Fork of the Merced River, which it overlooks, was in Pleistocene time the pathway of a good-sized glacier. Raymond Mountain (altitude 8,800 feet, or 2,682 meters) itself bore several small cirque glaciers at altitudes above 7,500 feet (2,286 meters). The ecologic significance of this remarkable relation of the grove to the glaciated areas above and below it is not yet fully understood. Several other groves of sequoias are similarly situated.

Wawona (altitude 4,096 feet, or 1,249 meters).—Wawona is in the valley of the South Fork of the Merced River, at the southern edge of the Yosemite region, the area of massive granite and uplands of great antiquity. The valley at Wawona is morphologically a "half yosemite." (See fig. 13.) On the south side it is bordered by hills of moderate declivity carved from well-jointed rocks; on the north side by sheer cliffs of massive granite that rise 3,000 feet (914 meters) to the brink of an undulating upland on which a large area of Miocene surface is preserved. The Chilnualna Falls leap from the mouth of a typical hanging valley on this upland 2,200 feet (671 meters) in height, in contrast to the tributary streams on the south side, which issue from deep-cut valleys without making any falls. The great height of the hanging valley of Chilnualna Creek is due not to glacial overdeepening of the main valley, but to the inability of the

GATEWAY BETWEEN EL CAPITAN AND CATHEDRAL ROCKS

The only constriction in the Yosemite Valley. It is flanked by two masses of exceptionally massive granite, El Capitan on the left and the Cathedral Rocks on the right. Immediately beyond the valley widens out to twice the breadth of the portal in an area where well jointed diorite and gabbro prevail. At left are the "Rockslides," over which the Big Oak Flat road is graded. Photograph copyright by J. T. Boysen. From U. S. Geol. Survey Prof. Paper 160, pl. 3, 1930.

A. TENAYA CANYON AND HALF DOME

The lower part of Tenaya Canyon has the typical U shape of a glacial canyon, but the upper part (not visible in view) has remained largely V shaped owing to the exceeding resistance of the massive granite. At the left is Basket Dome, at the right is Half Dome. Photograph by A. C. Pillsbury. From U. S. Geol. Survey Prof. Paper 160, pl. 8, *A*, 1930.

B. HANGING VALLEY OF YOSEMITE CREEK AND YOSEMITE FALLS, FROM GLACIER POINT

The most impressive, though not the most clean cut, hanging valley with a waterfall leaping from its mouth in the Yosemite region. Height of upper fall, 1,430 feet (436 meters); total height of the entire chain of falls and cascades 2,565 feet (782 meters). At the left is the overhanging rock of Glacier Point. Photograph by A. C. Pillsbury. From U. S. Geol. Survey Prof. Paper 160, pl. 9, *B*, 1930

streamlet to trench the massive granite as rapidly as the master stream has trenched the jointed granite.

Wawona is situated near the farthest point reached by the glacier that came down the valley of the South Fork. A remnant of a moraine, probably of the El Portal stage (Illinoian, or Riss), stands near the hotel. The granitic boulders in it are so thoroughly decomposed that they can be cut with a pick.

From Wawona northward to Chinquapin ranger station the road rises gradually along the deeply eroded slope at the western margin of the upland of massive granite. Two miles (3.2 kilometers) northeast of Chinquapin the road gains the top of this upland and thence winds among the wooded hills and grassy vales characteristic of the Miocene surface to the terminus near Glacier Point. The shallow valleys crossed by the road, which form part of the drainage basin of Bridalveil Creek, were glaciated only during the earlier stages of the Pleistocene epoch and so feebly that they retain their preglacial forms essentially unchanged.

Sentinel Dome (altitude 8,117 feet, or 2,474 meters).—Sentinel Dome is a residual knob of massive granite that projects above the general level of the Miocene surface. Like all the other domes in the Sierra Nevada, it consists of a single huge monolith and owes its smoothly rounded form to long-continued exfolia-

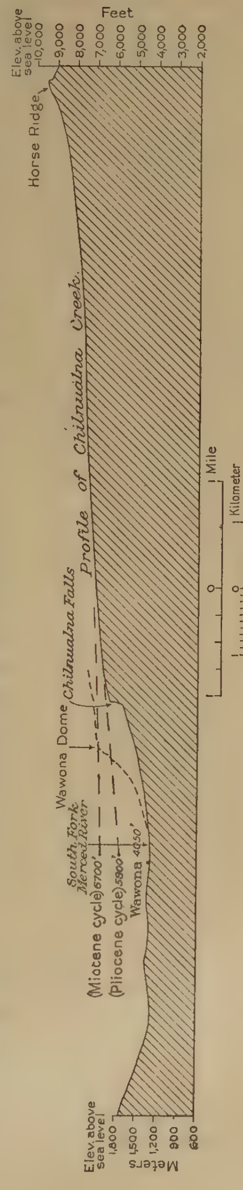


FIGURE 13.—Profile across the "half yosemite" at Wawona and along the hanging valley of Chilnualna Creek (22, fig. 11). The discordance between the hanging valley and the main valley is due not to glacial action but simply to the fact that the side stream has been unable to trench the massive granite of the upland as rapidly as the master stream has trenched the jointed rocks in its course. The hanging valley forms part of the Miocene surface. Horse Ridge is probably a remnant of a pre-Miocene surface

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tion. The rock is El Capitan granite, the porphyritic biotite granite of which the great cliff of El Capitan, in the Yosemite Valley, and adjoining parts of the uplands are largely made.

Along the driveway east of Sentinel Dome is a row of large erratic boulders which are the sole remnants of a moraine of the Glacier Point stage, the earliest stage of glaciation that can be definitely recognized in the Yosemite region (the correlative, presumably, of the Nebraskan (Günz) stage). The boulders consist of a distinctive facies of Sentinel granodiorite and are derived from the cliffs south of Glacier Point. They were, therefore, carried westward and 500 feet (152 meters) up the slope. The boulders indicate the highest level reached by the ice. Sentinel Dome was never overtopped, and glaciation has played no part in the development of its rounded form.

Glacier Point (altitude 7,214 feet, or 2,199 meters).—Glacier Point is a glacially truncated spur of Pliocene age on the south side of the Yosemite Valley. The vertical and remarkably straight cliff face that terminates the promontory was formed by the splitting off of successive rock sheets defined by vertical east-west master joints. The famous overhanging rock at Glacier Point (see pl. 11, *B*) is a remnant of a nearly horizontal sheet defined by locally developed horizontal joints.

No polish, striae, or other markings produced by glaciation exist on the rock platform at Glacier Point. The Yosemite Glacier of the Wisconsin stage did not rise high enough to sweep over the promontory, and although the ice of the earlier stages overrode it to considerable depth, sufficient time has since elapsed for the removal of all glacial markings and the wasting away of the rock to a depth of several feet. The circular basins that occur here and there in the surface of the rock are not potholes worn by rotating cobbles but cavities due to sharply localized weathering intensified by pools of water.

In the vicinity of the hotel is a thin sheet of morainal material of the El Portal stage (Illinoian, or Riss), containing boulders and fragments of rock derived from the Little Yosemite Valley and Mount Clark.

Panorama from Glacier Point.—From Glacier Point the observer looks down 3,200 feet (975 meters) into the Yosemite Valley. To the northeast is the profoundly glaciated U-shaped Tenaya Canyon. (See pl. 11, *A*.) To the southeast is the head of the Pleistocene gorge of the Merced, transformed by glaciation into a giant stairway, with steps controlled by master joints. From the upper step the Merced descends in the Nevada Fall, 594 feet (181 meters) in height; from the lowermost step it drops in the Vernal Fall, 317 feet (97 meters) in height. The top of the

Nevada Fall marks the approximate level of the Little Yosemite Valley, which was developed by glaciation from the Pliocene valley of the Merced. The Little Yosemite is largely masked from view by Liberty Cap and Mount Broderick, two huge roches moutonnées of massive granite.

On the divide between the Little Yosemite and Tenaya Canyon stands Half Dome (pl. 11, *A*), the most spectacular rock monument in the Sierra Nevada. It consists of a monolith 0.85 mile (1.36 kilometers) long in a northeasterly direction, a quarter of a mile (402 meters) wide, and 2,200 feet (670 meters) high. Its crown, back (southeast side), and two ends are rounded as a result of long-continued exfoliation; the sheer northwest face is almost plane, having been exposed relatively recently by the scaling off of parallel rock plates from a zone of nearly vertical joints. Half Dome is not a roche moutonnée. The Pleistocene ice did not reach within 500 feet (152 meters) of its crown, as is evident from the positions of the highest moraines on the neighboring uplands.

Beyond Half Dome is the higher massif of Clouds Rest (altitude 9,929 feet, or 3,027 meters), which is composed largely of massive granite and bears on its top a small remnant of a pre-Miocene surface of erosion. In the background are the serrate crests of the High Sierra, from which came the glaciers that converged upon the Yosemite Valley. The peaks attain altitudes of 12,000 to 13,000 feet (3,658 to 3,962 meters) and rise 2,000 to 3,000 feet (610 to 914 meters) above the Miocene surface.

Directly opposite Glacier Point, on the north side of the valley, are the Royal Arches, a unique piece of cliff sculpture produced by glacial plucking in an exfoliating mass of granite. Exfoliation here is on a colossal scale, some of the shells being more than 10 feet (3 meters) in thickness. Above the Royal Arches stands North Dome, a helmet-shaped exfoliation dome. Northeast of North Dome is the strongly asymmetric Basket Dome.

West of North Dome are the hanging valleys of the two forks of Indian Creek—typical valleys of the Pliocene landscape which have suffered but slight change by glaciation. Still farther west the Yosemite Falls leap from a hanging valley 2,565 feet (782 meters) in height. The upper fall, 1,430 feet (436 meters) high, is probably the highest waterfall of the leaping type in the world. The lower mile of the hanging valley belongs to the Pliocene cycle; the rest of its course, up to the foot of Mount Hoffmann, to the Miocene cycle.

The northern sky line is formed by the hills of the Miocene upland, surmounted here and there by ridges of moderate height that are probably of pre-Miocene age.

Descent into Yosemite Valley.—From Glacier Point the excursion party retraces its steps as far as Chinquapin. Thence it descends by the new highway into the Yosemite Valley. This highway is laid over the bare granite surface of Turtleback Dome, an imperfect dome which owes its smoothly rounded contours not to exfoliation, the granite being divided by widely spaced master joints, but to the grinding action of the overriding Yosemite glacier. It was overridden only during the earlier glacial stages, and the granite has since lost all of its polish and has wasted away to a depth of several feet. The dioritic inclusions in the granite tend to remain standing in relief.

Turtleback Dome forms part of a broad rock bench that flanks the narrow Pleistocene gorge through which the Merced River leaves the Yosemite Valley. This bench is a remnant of the floor of the Pliocene valley of the Merced. The gorge has the appearance of being wholly a product of stream erosion, yet it has suffered glaciation at least twice (during the Glacier Point and El Portal stages). Its narrowness is due to the fact that the Yosemite Glacier was unable to quarry the sparsely jointed granite but could only abrade its surface.

The road next passes through a tunnel 4,230 feet (1,289 meters) long, cut through a low spur that projects into the old Pliocene valley of the Merced. Upon emerging from the tunnel the traveler beholds a splendid general view of the Yosemite Valley. (See pl. 10.) Directly ahead is the Bridalveil Fall, 620 feet (189 meters) in height, which leaps from a hanging gulch projecting into the main valley on the promontory of the Cathedral Rocks. The gulch is a product of the Pleistocene cycle and was left hanging by the glacial overdeepening and widening of the Yosemite Valley. It terminates 850 feet (269 meters) above the valley. The depth of glacial excavation in the valley indicated by the profile of the gulch is about 700 feet (213 meters). (See fig. 12.)

On the opposite side of the valley is the great cliff of El Capitan, 3,000 feet (914 meters) in height, which reaches directly up to the level of the Miocene surface. The rounded crown of El Capitan, 500 feet (152 meters) in height, is a hill on that surface. El Capitan is composed of interlocking intrusions of El Capitan granite, Taft granite, and diorite crossed by dikes of aplite and pegmatite, yet the mass as a whole is essentially a monolith.

A short distance west of El Capitan is the Ribbon Fall, the highest waterfall in the Yosemite region. It makes an almost clear leap of 1,612 feet (491 meters) from a hanging valley on the Miocene upland that terminates at a height of 3,050 feet (930 meters) above the floor of the Yosemite Valley. This

valley was already 900 feet (274 meters) above the Yosemite Valley at the end of the Pliocene cycle, in consequence of the inability of its streamlet to keep step with the rapid trenching of the Merced River. (See fig 12.)

A mile east of El Capitan is the massif of the Three Brothers, distinguished by smooth westward-sloping rooflike facets controlled by oblique master joints. On the opposite (south) side of the valley Sentinel Rock reveals in its sculpture the dominant influence of nearly vertical master joints with northeasterly trend. Many cliff faces and facets in the Yosemite Valley are controlled by joints of this northeasterly system, as is readily evident from the detailed topographic map of the valley. These joints traverse a number of different granitic intrusions.

The nearly level floor of the Yosemite Valley consists largely of granite sand deposited by the Merced River in a glacial lake basin 5½ miles (8.8 kilometers) in length. Its mean altitude is about 3,960 feet (1,207 meters). The lake was impounded, opposite the Cathederal Rocks, by a moraine dam resting in all probability on a swell in the glacially excavated rock floor of the valley. No borings have been made to determine the depth of the basin.

Yosemite to Tioga Pass.—The road by which the party leaves the Yosemite Valley leads up across a talus 3,000 feet (914 meters) in height, known locally as the Rockslides. This talus is composed almost wholly of gabbro, a material which, in contrast to the siliceous granites, is well jointed throughout and therefore incapable of maintaining a sheer cliff profile.

From the road on the talus one looks down upon the Bridalveil Meadow. At the head of this meadow, masked by timber, is the terminal moraine that marks the farthest limits reached by the Yosemite Glacier of the Wisconsin (Würm) stage.

About 2 miles west of the Rockslides the road crosses the highest lateral moraine left by the Yosemite Glacier of the El Portal stage (Illinoian, or Riss). That glacier therefore had at this point a thickness of nearly 2,200 feet (670 meters). It extended 7 miles (11 kilometers) farther, ending in the Merced Canyon near the site of El Portal.

West of the bridge across Cascade Creek the road cuts through small bodies of morainal material of the El Portal stage left by the Cascade Glacier, which was tributary to the Yosemite Glacier. About half a mile (0.8 kilometers) west of the bridge the last morainal material is seen, and from this point on the country traversed is unglaciated for many miles. The valleys followed by the road as a rule belong to the Pliocene cycle; the upland surfaces between them to the Miocene cycle. Near the western boundary of the Yosemite National Park the Tuolumne

Grove of Bigtrees is passed. It is one of the lesser groves of sequoias in the Sierra Nevada, and only a few of the trees are visible from the road.

The road continues in a northwesterly direction as far as the Carl Inn, on the South Fork of the Tuolumne River, and thence swings abruptly to the east and the northeast, winding among the wooded hills and gaining gradually the level of the Miocene upland, which here ranges from about 7,500 to 8,500 feet (2,286 to 2,590 meters) in altitude. At its northernmost point the road is within less than 1 mile (1.6 kilometers) from the south brink of the Grand Canyon of the Tuolumne River.

From this point the road turns southeastward over the Miocene upland. It crosses the broad and extremely rough glaciated valley of Yosemite Creek, skirts the south base of Mount Hoffman (altitude 10,921 feet, or 3,329 meters), on whose summits are preserved several remnants of a pre-Miocene surface, and then descends into the Tenaya Basin, which is a part of the Pliocene surface, greatly modified by glaciation. Tenaya Lake (altitude 8,141 feet, or 2,482 meters) is surrounded by large areas of glacially polished granite (Half Dome quartz monzonite), strewn with erratic blocks. The ice attained a depth in the Tenaya Basin of fully 2,000 feet (610 meters), overtopping Polly Dome. The ice mass was only in small part of local origin; the bulk of it came from the Tuolumne Basin, to the northeast, over a low, irregular divide.

At Tenaya Lake the Half Dome quartz monzonite, which is the country rock over a large part of the upland traversed, becomes obscurely porphyritic near the contact with the Cathedral Peak granite, to the east, which is itself very conspicuously porphyritic. The phenocrysts of the Cathedral Peak granite, which measure 2 to 4 inches (5 to 10 centimeters) in length, are to be seen in many places along the road beginning at a point about 2 miles (3.2 kilometers) above Tenaya Lake.

The divide between the Tenaya and Tuolumne Basins is marked by many knobs and imperfect domes, all severely worn by the overriding ice. The outstanding rock monument is Fairview Dome, on the south side of the road, which stands 1,200 feet (366 meters) high. It owes its sugar-loaf form to glacial corrosion rather than to exfoliation.

Immediately east of Fairview Dome the road enters the Tuolumne Meadows (altitude 8,500 feet, or 2,590 meters), which extend for 3 miles (4.8 kilometers) along the upper course of the Tuolumne River and contain the second largest tourist center in the Yosemite National Park. The broad-floored valley in which the meadows are situated and its two branch

valleys leading to Mount Lyell and Mount Dana are representative of the glaciated valleys of the Pliocene cycle that occur throughout the High Sierra. The head of the Pleistocene gorge of the Tuolumne River is just below the Tuolumne Meadows. The wooded benches 700 to 1,000 feet (213 to 305 meters) in height that flank the meadows are remnants of the Miocene surface, and the mountain ranges that stand above the benches—the Cathedral Range, Kuna Crest, and the main crest of the Sierra Nevada—reach up to remnants of the early Eocene surface, which lie at altitudes of 11,500 to 13,000 feet (3,505 to 3,962 meters). The largest of these remnants is on Mount Dana, immediately east of Tioga Pass. Some of the Pliocene valleys have remnants of Miocene valleys at their extreme heads. The most notable remnant of that kind is at the head of the South Fork of the Dana Fork, between Mono Pass and Parker Pass. Tioga Pass (altitude 9,941 feet, or 3,030 meters) is between two opposing valleys of the Pliocene cycle.

Cathedral Peak granite is to be seen throughout the greater part of the Tuolumne Basin. The Cathedral Range, to the south, and the mountains north of the basin are in large part made of it. Near the Soda Springs, however, is a body of Johnson granite porphyry intruded in the center of the large mass of Cathedral Peak granite. The latter in turn is surrounded by Half Dome quartz monzonite, which is to be seen for some distance along the Dana Fork. For the last 2 miles (3.2 kilometers) to Tioga Pass the road passes over Sentinel granodiorite, which forms a belt around the Half Dome quartz monzonite. North of Tioga Pass itself begin the quartzites and other metamorphic rocks that make up the crest of the range.

NOTE.—For bibliography see pp. 39–40.

EASTERN SLOPE OF THE SIERRA NEVADA

By ELIOT BLACKWELDER

INTRODUCTION

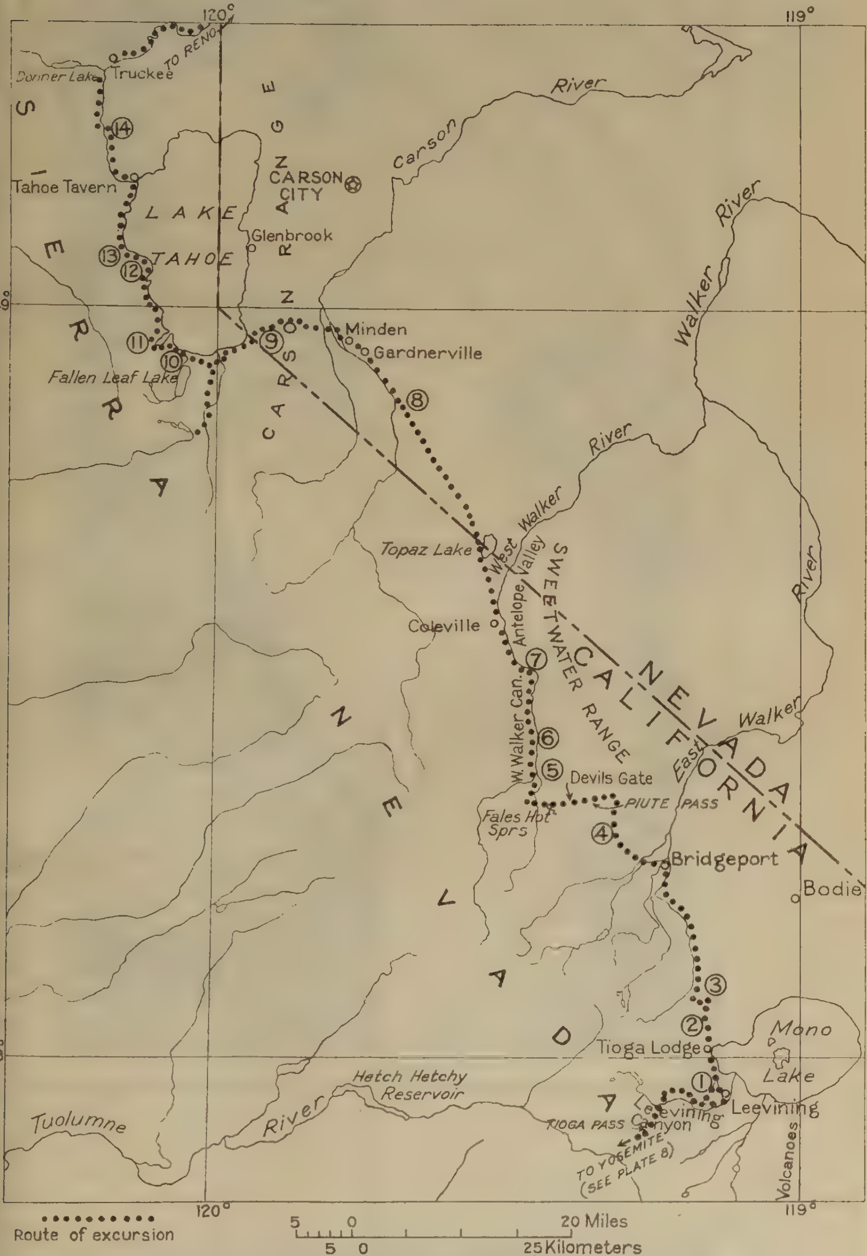
The eastern slope of the Sierra Nevada is in many respects unlike the western. The altitude is higher (5,000 to 8,000 feet, or 1,524 to 2,438 meters), and the climate is colder and more arid. At this latitude there is no sharp line of demarcation either geologically or topographically between the Sierra Nevada and the Basin Range province to the east. The two merge in a broad plexus of mountains and valleys within which boundaries are largely arbitrary. Only locally, at Mono Lake and near Lake Tahoe, is the base of the Sierra well defined and scarplike.

The annual precipitation averages from 10 to 50 inches (254 to 1,270 millimeters) according to the altitude. It comes in the form of occasional snows from November to June and brief but sometimes severe thunder showers in summer. Only the months of June, July, and August are relatively free from frost in the valleys. The temperature commonly ranges from about −20° F. (−29° C.) in January to about 100° F. (38° C.) in midsummer.

The dense forest of the humid western slope thins out rapidly, as it crosses the divide, and comprises little but the pines (*Pinus jeffreyi*, etc.) and junipers. At the north this attenuated forest extends eastward almost to Reno, but at the south, near Mono Lake, even the scattered groves fail to reach the base of the main range. They are replaced by the sagebrush (*Artemisia*), which covers vast areas in the northern half of the Basin Range province. Along streams and around damp spots willows, poplars, and aspens are characteristic in the sagebrush zone.

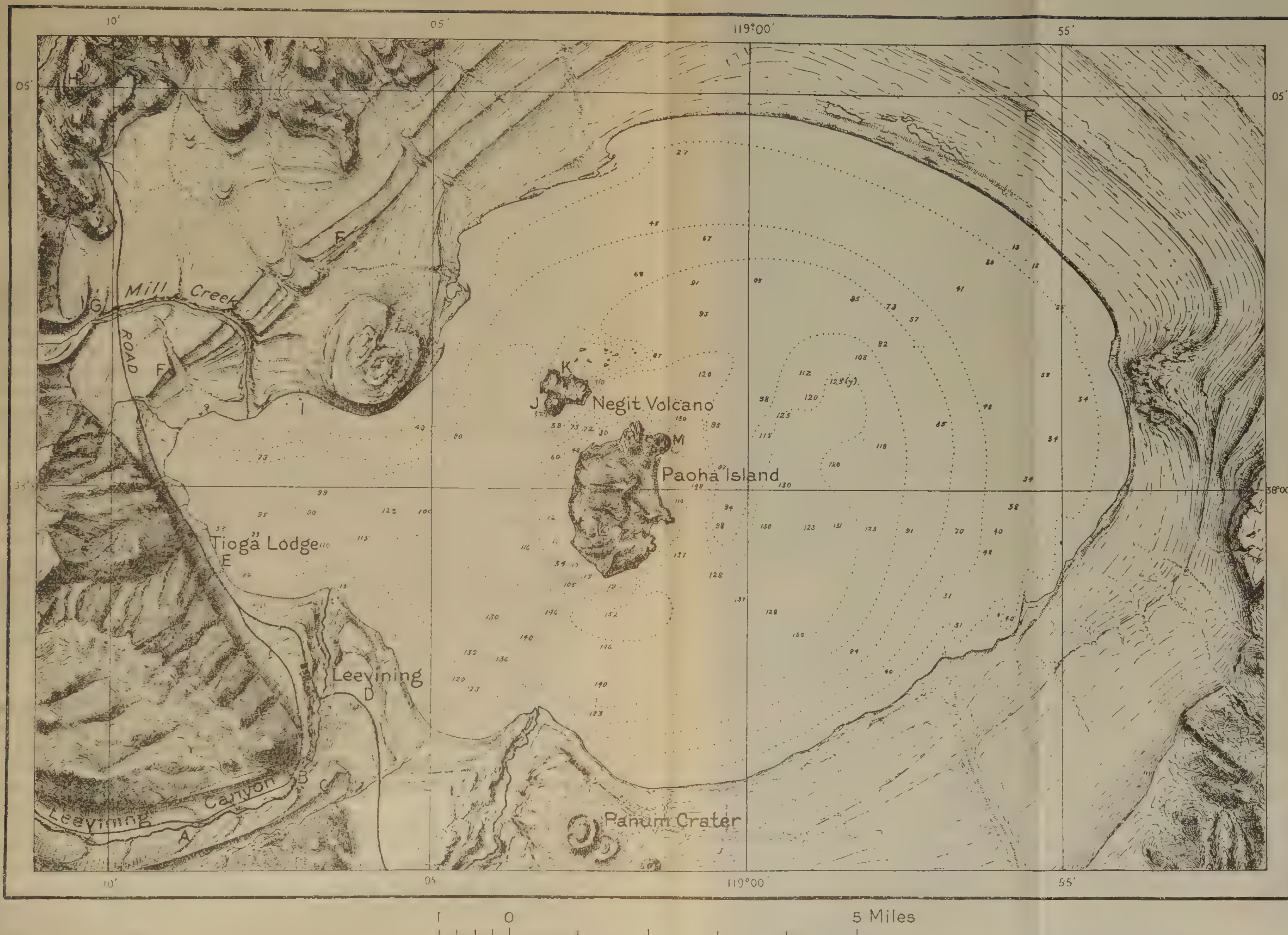
Before 1850 the region abounded with deer, pronghorn antelope, black and grizzly bears, wolves, coyotes, and jack rabbits, but all are now rare except the rabbits. Birds are plentiful and varied, and there are many small forms of life of interest to the zoologist. Along the route can be seen gulls, pelicans, ducks, avocets, grebes, several kinds of hawks (*Buteo*, etc.), blackbirds, meadow larks, horned larks, and grass finches. Occasionally the interesting water ouzel or dipper (*Cinclus*) is seen along the roaring mountain creeks, and the rock wren (*Salpinctes*) often challenges the intruder who stops to look at a rock outcrop in the sagebrush zone. Among reptiles the rattlesnake (*Crotalus*) has been nearly exterminated, even from the lowlands, where it was once common. Lake Tahoe and the larger streams contain several species of trout and other fishes, many of which have been artificially introduced. The supply is maintained by State fish hatcheries at intervals along the range. Mono Lake, although devoid of fish, contains vast numbers of small crustaceans and insect larvae, which alone have succeeded in adapting themselves to its strongly alkaline water.

After the initial exploration of the Far West, from 1825 to 1850, white settlers and miners entered this region, largely between 1850 and 1860. The development of hydroelectric power has become important since 1900, and now the region is used in summer largely as a recreation ground for visitors from the cities of California. The resident population is sparse, and the villages are widely separated by broad uninhabited areas used only for sheep grazing.



MAP OF EASTERN SLOPE OF SIERRA NEVADA

Numbers in circles indicate localities referred to in text.



MAP OF MONO LAKE

After I. C. Russell, U. S. Geol. Survey Eighth Ann. Rept., pt. 1, pl. 19, 1889. A, Frontal moraine of the last glacial retreat; B, terminal moraine (Tioga stage); C, truncated lateral moraine (Tahoe stage); D, glacial delta (Tioga stage); E, lake tufa and gravel deposits on the mountain scarp; F, late Pleistocene gravel bars; G, lateral moraine of the Lundy Canyon glacier (Tahoe stage); H, ancient till (Sherwin stage) resting upon granite; I, domes and pillars of lake tufa; J, recent basaltic cinder cone; K, basalt flow; L, eroded hills of diatomite and clay (Miocene?); M, small recent basaltic craters.

GEOLOGY

State of knowledge.—The northern part of the region was reconnoitered by the Fortieth Parallel Survey in the seventies. In the eighties and nineties detailed reports were prepared on the Mono Basin and the west side of the Tahoe-Truckee basin. Other studies of special details, such as the glacial history and certain mining districts, have been made in the last few decades. Most of the region is, however, unmapped geologically, and even its larger geologic problems are as yet unsettled. Nowhere has a thorough and comprehensive study been made, in the last 30 years, of any part of the strip with which this guide is concerned.

Stratigraphy and structure.—In the metamorphic pre-Cretaceous terranes no recognizable fossils have been found, and but few formations are differentiated. Certain slates, metaquartzites, and effusive volcanic rocks are thought to be Triassic. Other slates, metaquartzites, and marbles are probably Devonian and Carboniferous. All have been compressed into isoclinal folds which strike northwestward and have been intruded by the great complex batholith of probably late Jurassic age. The thickness of these ancient terranes, although only conjectural, must have amounted to thousands of feet.

For many years sporadic attempts to develop mines of gold and some other metals have been made in this region, but without much success. There is no great mining district here comparable to the Mother Lode on the west slope.

The metamorphic rocks are overlain discordantly by a volcanic series which is probably in large part of upper Miocene age but may include earlier deposits and is known to contain some Pliocene and Pleistocene rocks. The prevalent type is brown andesitic agglomerate, with much tuff and a few flows. From Mono Lake southward a buff or tawny rhyolitic series, which may be Pliocene, predominates; and near Truckee some basalt of probable early Pleistocene age overlies the andesite. Locally stream gravel, sand, and silt are intercalated in the volcanic series, and even more rarely lacustrine clay, diatomite, and white volcanic ash appear. Very few fossils have been found, but they comprise enough plants and fragmentary mammal bones to indicate the age of certain beds.

The Miocene and Pliocene series have been generally but only gently folded, leaving dips commonly 10° to 15° and rarely over 45°. At widely spaced intervals there are steep faults, on some of which displacements of several thousand feet have occurred. Most of these faults trend northwestward. They are of several ages.

The Pleistocene deposits are rather free from volcanic material, except in the basin of Mono Lake. There basaltic cinder cones and flows rise in the lake and among the mountains to the northeast, and a string of acidic cones and domes of obsidian, pumice, and ash extends from the lake southward some 25 miles (40 kilometers). These are of late Pleistocene and perhaps even Recent age, but there are in the locality no steam vents, fumaroles, or other present indications of dormant volcanic energy.

Glacial moraines, with the usual associated lake and stream deposits, occur in most of the larger valleys that indent the Sierra Nevada. Recent studies have served to differentiate four stages, known as the McGee, Sherwin, Tahoe, and Tioga stages. The Tioga was the most recent. All except the oldest are readily recognized along the route of travel, and boulders of the McGee stage are visible from the road.

The upland soils of the region are immature and appear to be in large measure of eolian origin. The plains are made up of alluvium, much of which is gravelly or coarse arkose sand, but thin loesslike coats have been deposited on the older alluvial terraces. Landslides and mud flows are common in the drier parts of the district.

Geologic history and geomorphology.—The main events in the geologic history of the Sierra Nevada have been outlined on pages 33–39. On the eastern slope the story is less completely known but seems to be similar. Long periods of marine and emergent conditions in Paleozoic and early Mesozoic time were succeeded by the late Jurassic orogeny, which revolutionized the region. Prolonged erosion, modified by dimly recorded warpings and other changes, continued until about the middle of the Miocene period.

Then a series of volcanoes spread vast quantities of cinders and ash over the entire northern part of the Sierra and eastward many miles into Nevada. Many of the deposits are mud flows; others are well-sorted river deposits derived from the volcanic débris. Now and then a lava flow was added to the growing mass, but nowhere did the flows predominate. This formation filled the shallow valleys of Miocene time, buried the hills, and overtopped some of the higher mountains, eventually attaining a thickness of over 3,000 feet (914 meters). The region must then have presented a volcanic landscape, like that of the Auvergne, in central France. Subsequent erosion has removed about two-thirds of the volcanic sheet, demolished the cones, and left only scattered necks of intrusive rock rising above the fragmental ejecta. Some of these necks have been identified, along the divide west of Lake Tahoe.

Block faulting and warping initiated a new geomorphic cycle, probably at some time in the Pliocene period. The scarps then formed have been entirely demolished by erosion. Uplift, with warping and local faulting, appears to have continued at long intervals down to recent times, while erosion carved the unstable mass into canyons, ridges, and peaks. Nearly all the features of the existing landscape are of Pleistocene age, and nearly all appear to be due solely to erosion. The exceptions are supposedly tectonic depressions of the Tahoe, Carson, Antelope, and Mono basins, the volcanic cones near Mono Lake, and the minor constructional features left by streams, glaciers, and lakes.

There is general evidence in the Sierra Nevada that early Pleistocene time was marked by the elevation of the region several thousand feet, and indeed there are some indications that the movement is still in progress, even if at a slower rate. In response to this uplift the streams have trenched deep canyons across the upland, and temporary glaciers have excavated the heads of such canyons.

Here, as elsewhere, the climate of the Pleistocene period was pulsatory, and so epochs of cold alternated with warmer, drier epochs four or five times. During the cold epochs glaciers crept down the valleys to lengths of 10 or even 20 miles (16 to 32 kilometers), but in the warmer epochs they withdrew or quite disappeared. The first glacial epoch (McGee stage) came before the present canyons and deep basins were formed, or at least before they had been cut down within some 3,000 feet (914 meters) of their present levels. Its moraines have been almost entirely destroyed by erosion. After a very long interglacial stage, in which the topography was carved into much more nearly its present condition, the glacial climate returned (Sherwin stage). The ice tongues were longer at this time than at any other, so far as now known, but their deposits have been so much eroded that their original outlines can no longer be mapped in full. There are strong indications that the Sherwin stage really comprises two, but the substages are very difficult to distinguish and correlate with confidence. In the next warm epoch canyons 500 to 1,000 feet (152 to 305 meters) deep were cut in hard rocks, and broad basins in soft deposits were excavated to depths of hundreds of feet. Locally volcanic eruptions poured lava over the basin floors and blanketed the district south of Mono Lake with gray ash.

In late Pleistocene time there occurred two glacial advances separated by a warm episode of deglaciation. The moraines made during the earlier advance (Tahoe stage) were much larger than the later ones, and both are still well preserved. During

the last interglacial stage, which is estimated to have been three to five times as long as the postglacial epoch, streams cut channels 30 to 100 feet (10 to 30 meters) deep in rock and breached the terminal moraines widely. A few lava flows and more ash were laid down over the moraines south of Mono Lake, and the cirques along the Sierra Nevada crest were much softened and obscured by talus. The effects of the last glaciation (Tioga stage), which is correlated with the Wisconsin stage of the eastern United States and the Würm stage of Europe, are still so fresh that it is difficult to believe that they are thousands of years old. Glacial surfaces retain their polish; lakes remain unfilled; streams tumble over moraines and have made only shallow ditches in the solid rock.

The two large lakes, Mono and Tahoe, are not known to have existed before the Tahoe stage, although it is inherently probable that there were lakes in all the closed basins during each of the cool, moist epochs.

ITINERARY, TIOGA PASS TO TRUCKEE

[See pl. 12]

76.7 (123.4).[8] Tioga Pass (altitude 9,950 feet, or 3,033 meters). Here the crest of the Sierra Nevada is reached, and the road begins to descend the much shorter eastern slope of the range. In doing so it follows roughly the eastern margin of the batholith. The contact with the metamorphic sedimentary rocks is obscure where it is crossed by the road north of the pass. Mount Dana (altitude 13,050 feet, or 3,978 meters), on the east, includes both formations. In latest Pleistocene time the pass was occupied by a thin body of glacial ice which flowed both north and south. Tioga Lake, on the north, occupies a hollow in the bed of this glacier.

79.6 (128.1). In ice-worn outcrops on the shore of Ellery Lake the black slates and quartzites (Triassic?) strike parallel with the general trend of the range. In the mountain side to the southeast the contact between these strata and a marginal stock of the granodiorite can be traced.

79.9 (128.6). The road here enters Leevining Canyon. The creek is now diverted for electric power. The broad talus slopes of granite to the northeast have developed largely since the last glacier retreated. From the cliff ahead can be seen glimpses of the Mono Basin, with its remarkable lake and volcanoes.

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[8] Figures indicate distance from Yosemite in miles, with kilometers in parentheses.

85.7 (137.9). In the next 2 miles (3.2 kilometers) the traveler sees on the floor of the valley a series of low frontal moraines of the Tioga glacial stage and on both flanks high lateral moraines that include both Tioga and Tahoe stages. The terminal moraine of the Tioga stage constricts the valley just beyond the forest ranger station.

90.2 (145.2). [1] [9] This point on the ancient delta of Leevining Creek affords a fine view of the Mono Basin, with its many interesting geologic features. In late Pleistocene time Mono Lake stood at the level of its highest terrace, which is now obscurely traced on the mountain slope to the west, about 685 feet (209 meters) above the present shore. There were apparently at least two such expansions of the lake coincident with the last two stages of glaciation. The glacier of the Tahoe stage built the bulky lateral moraine visible to the south, and during the retreat of the lake from its greatest expansion in the Tioga stage its waves carved a series of terraces upon the end of the moraine. In both stages the stream built and afterward trenched the delta.

To the southeast rises a range of gray volcanoes which consist of obsidian, pumice, and ash. Some of them have well-defined craters, but the majority are jagged glass domes in which the viscous acidic lava was scarcely able to issue beyond the vent. There are three well-defined but steep obsidian flows, and the one on the west side is visible 6 miles (9.6 kilometers) south of the lake. These volcanoes are of late Pleistocene age. The low northernmost cone, which consists of an obsidian plug surrounded by a collar of lapilli, is even postglacial.

Mono Lake (altitude 6,415 feet, or 1,955 meters; see pl. 13) is a soda lake now about 155 feet (47 meters) deep. The salinity is about 5.1 per cent and the chief components are Na_2CO_3 37.8 per cent, NaCl 35.3 per cent, Na_2SO_4 19.6 per cent, KCl 4.3 per cent, and others 3.0 per cent. As the city of Los Angeles will soon begin to divert the tributary streams into its aqueduct, the lake is destined in the next few decades to shrink and become more concentrated. Of the islands in the lake, the larger one consists of gently folded Pliocene(?) lake deposits including marl and diatomite, upon which some very young but small basaltic volcanoes are superposed. The darker island to the north is a young cinder cone on a flow of basalt. The origin of the lake basin is unknown, but warping involving minor faulting is the most favored theory. It is possible that obstruction by volcanic flows may have been an important factor.

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[9] Numbers in brackets refer to map, Plate 12.

91.4 (147). The scarp here is plastered locally with calcareous tufa that was formed by blue-green algae in the waters of Mono Lake at the time of its last expansion. Blocks of the dendritic and thinolitic varieties may be seen along the roadway just after it descends to the lake. Such deposits occur only at widely scattered intervals along the old lake terraces.

96.7 (155.6). Along this gentle slope can be seen several well-defined gravel beaches of the Pleistocene Mono Lake. Isolated pillars of calcareous tufa rise from these old beaches and the present shore. The black hill 3 miles (4.8 kilometers) farther east is a much eroded basaltic cinder cone of an earlier series.

97.9 (157.6). [2] From Mill Canyon on the southwest another large glacier issued during the Tahoe stage and built a moraine upon the plain. Later the terminal moraine was eroded away by the stream, leaving only the lateral ridges. During the Tioga stage the waves on greater Mono Lake carved a series of terraces on the moraines, while the glacier of the same age barely reached the mouth of the canyon. The altitude of the highest terrace is 7,110 feet (2,167 meters). From this point can be seen, a few degrees west of north and on the smooth mountain of granite up which the road winds, a thick deposit of much older glacial till. Its original margin has been entirely eroded away, but the fresh road cuts show clearly the nature of the material.

101.5 (163.3). [3] Having ascended the slope of granite in which decay produces exfoliate boulders and sand, the road here turns northward and enters, at an altitude of 7,800 feet (2,377 meters), the ancient till of the Sherwin glacial stage. To the south a last splendid view of the Mono Basin reveals also the snowy peaks of the Sierra Nevada, which range themselves in the background for a distance of 50 miles (80 kilometers).

102.9 (165.5). Virginia Creek on the left descends from its canyon in hard metamorphic rocks, such as hornfels and metaquartzite, and turns northward through a canyon in Miocene(?) andesitic pyroclastic rocks and flows. Beyond the mouth of the canyon extend two sets of moraines, the younger (Tioga stage) bouldery and but little eroded, the older (Tahoe stage) smooth and much more bulky. Beyond these to the northwest and even to the northeast the still older Sherwin till, now greatly eroded, covers broad areas. For 2 miles (3.2 kilometers) it is exposed in road cuts, where striated pebbles of the hard quartzose rocks can be readily found.

107.2 (172.5). To the east are seen only the hills of the andesitic series, but on the west the Sherwin till covers this formation, except where canyons have been cut through into the rock. Another bulky lateral moraine of the Tahoe stage sweeps down from Green Canyon, southwest of this point. The road now descends into the canyon of Virginia Creek, in which an unsuccessful attempt at placer mining for gold has recently been made.

Figure 14.—Sketch map of glacial deposits in Bridgeport Basin

116.7 (187.7). Bridgeport (altitude 6,473 feet, or 1,973 meters). Just before entering this village the road passes a typical settlement of the Piute Indians, a remnant of the tribe which originally held all this region.

The basin (see figs. 14, 15), excavated out of soft pyroclastic deposits of the andesitic series, is now floored with gravel washed out of the glacial canyon to the southwest. The bulky south lateral moraine of the Robinson Creek glacier juts out several miles into the plain, but its terminal moraine is now largely eroded away and replaced by a gravel fan. The extremely ragged crest of the Sierra Nevada at the head of that canyon has been carved from a granitic offshoot from the great batholith which there invades the prevailing metamorphic series.

124.2 (199.9). [4] The bouldery hills on the left are a greatly eroded moraine of the Sherwin stage, left by a large glacier that descended Long Valley from the west. To the north the summits of the weakly glaciated Sweetwater Range (altitude 11,650 feet, or 3,551 meters) are visible. These mountains consist of pre-Jurassic igneous and metamorphic rocks partly concealed by the gently folded and faulted Miocene volcanic series. The surface of deposition was mountainous and is therefore very irregular.

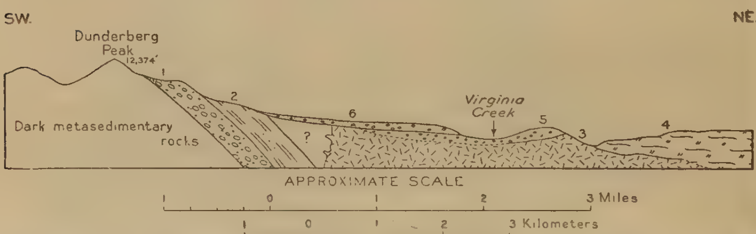

FIGURE 15.—Cross section of divide between Mono and Bridgeport Basins (about 7 miles, or 11 kilometers). 1, Dark metaquartzite and conglomerate; 2, dark metagraywacke and hornfels; 3, massive granodiorite (late Jurassic); 4, andesitic tuff, agglomerate, and flows (upper Miocene?); 5, ancient till (Sherwin stage); 6, younger lateral moraines (Tahoe and Tioga stages)

129.7 (208.7). The narrows in granite known as the Devil's Gate (altitude 7,480 feet, or 2,280 meters) shows conspicuously the exfoliation and staining of joint blocks caused by chemical decay. The notch appears to have been cut by a large glacial stream which issued, in the Sherwin stage, from the great West Walker Glacier and ran southeastward into the Bridgeport Basin. The growth of local alluvial fans has since buried the old channel.

131.2 (211.1). A large hot spring (temperature 175° F., or 79° C.) issues here at Fales Hotel. Older deposits of travertine are plentiful on the slope to the right, and with the aid of bright-colored algae the stream is now forming new calcareous deposits along its channel.

132.1 (212.7). Ahead can be seen several ridges of the ill-defined Sierra Nevada front, carved from rhyolitic and andesitic Miocene pyroclastic rocks, which rest upon granite. The road soon enters the thick fluvioglacial deposits of Sherwin age, now deeply eroded. Still older glaciation is represented by isolated granite boulders 1,500 feet (457 meters) up the mountain sides to the north and south of the hot spring.

135 (217.2). [5] Having descended to the West Walker River (altitude 6,950 feet, or 2,118 meters), the road now turns northward and enters an open space which has been excavated out of the ancient Sherwin glacial beds and underlying pyroclastic rocks. This basin is now occupied by a well-defined moraine lobe of Tahoe age, still well preserved. The adjacent road cut shows this till and its soil cover. On the isolated 1,200-foot (366-meter) hill due west and on the high terraces north of it the remnants of Sherwin till are found, but the isolated boulders of the earliest (McGee) stage are barely visible upon summits 2,500 feet (762 meters) above the river to the northwest and north. The canyon to the north was cut largely during the first interglacial epoch but was deepened several hundred feet during the second.

137.6 (221.4). Near the bridge over the West Walker River road cuts show the glaciofluvial gravel (Tahoe stage) lying on rock terraces of basaltic lava and tuff. The low eroded terminal moraine of the old glacier can be seen just ahead. In the higher slope to the right the white crags are rhyolitic tuff, which is interbedded with the basic pyroclastic rocks and lava. Here the road enters a canyon 2,000 to 3,000 feet (610 to 914 meters) deep and about 10 miles (16 kilometers) long, carved largely out of jointed granitic rock, which is overlain irregularly by the volcanic Miocene series.

141.5 (227.7). [6] Old tollhouse. On the ridge east of the river and 1,260 feet (384 meters) above it the last remnant of the Sherwin till of the ancient Walker Glacier can be recognized by the gray boulders of granite resting upon the basic volcanic rocks.

148.3 (238.6). [7] The canyon here opens out into Antelope Valley, which is probably a tectonic depression. The terrace on the right reveals gravel resting upon truncated granite, much as at the south entrance.

149.3 (240.3). For the next 14 miles (22 kilometers) the road follows the base of a compound scarp that is probably a true fault scarp, now somewhat eroded. Near by a series of buttresses probably represents minor fault blocks or wedges that did not rise as much as the main block. Some of these wedges consist of gravel as well as hard rocks.

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151.8 (244.3). Coleville (altitude 5,150 feet or 1,570 meters). The scarp on the west here consists of granite, and the long slope on the east is backed with the andesitic series. It is supposed to be part of a block tilted toward the west and faulted on the east side.

158.5 (255.1). Topaz Lake is held in by an artificial dam. It supplies water to ranches in Nevada, to the northeast. White pelicans and other water birds find it attractive. That the lowest point of this depression should be at the very base of the western scarp again suggests fault-block topography, even though the original tectonic features have been much eroded. On the west the granite has given way to slate and hornfels. From the lake northward the andesitic series conceals all the older rocks for some 15 miles (24 kilometers).

172 (276.8). The scarp on the west gradually dies out, leaving maturely dissected hills. At the north end of a small sagebrush plain the road descends into a ravine, where piñon and juniper trees are plentiful. The rocks in these slopes are pyroclastics, lava, and gravel of the Miocene andesitic series all gently folded.

178.7 (287.6). [8] The traveler descending into the Carson Valley sees to the northeast low dissected hills of Miocene (?) volcanic deposits and on the left (northwest) the imposing scarp of the Carson Range, an offshoot of the Sierra Nevada which rises from 5,000 feet (1,524 meters) at the base to nearly 11,000 feet (3,353 meters) at the summit. The range consists largely of granitic rock. It was but slightly glaciated even in the Tahoe stage. The aggraded alluvial floor of the basin conceals all rocks to an unknown depth. Like Antelope Basin, Carson Valley is generally believed to be of tectonic origin.

Here at the edge of a terrace an excavation shows the brown stream gravel, which appears to have been deposited in the drier pre-Tahoe interglacial stage of the late Pleistocene.

184.7 (297.2). Minden (altitude 4,730 feet, or 1,442 meters). The villages of Gardnerville and Minden are situated in the midst of the recent alluvial plain of the Carson River, which rises in the Sierra Nevada, on the southwest.

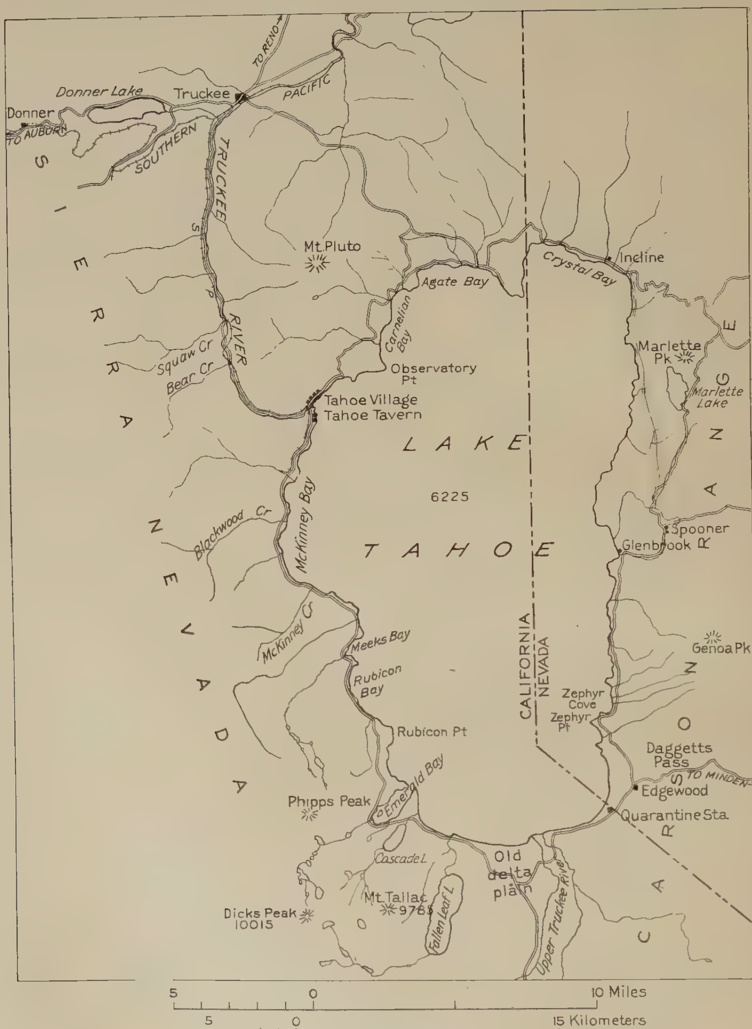
189.4 (305.2). Here the Carson River flows within a mile (1.6 kilometers) of the base of the great scarp. (See pl. 14, *A*.) To the north along the foot of the slope can be seen, when the light is favorable, a 20-foot (6-meter) scarplet due to a renewal of fault movement in rather recent time.

A. FAULT SCARP OF CARSON RANGE

View northwest of Minden, Nevada, showing a recent dislocation (20–30 feet, or 6–9 meters) along the east base of the range.

B. PRE-LAHONTAN CHANNEL WEST OF HAZEN, NEVADA

The Truckee River formerly continued east from a point near Wadsworth and flowed into a pre-Lahontan lake occupying the present playa. The outlet of the lake is traced by a dark line. A channel 200 to 300 feet (61 to 91 meters) wide and 30 to 40 feet (9 to 12 meters) deep has been cut in a low ridge of Tertiary sediments. From this point the river flowed on eastward into the Carson Sink. Photograph by Curtis.



SKETCH MAP OF LAKE TAHOE AND VICINITY

199.8 (321.6). [9] Quarantine station. Having ascended the steep front of the Carson Range, crossed its divide at an altitude of 7,475 feet (2,278 meters), and descended to Lake Tahoe, the road now reenters California. This beautiful fresh-water lake is 21 miles (33.7 kilometers) long and 12 miles (19.3 kilometers) wide. Its greatest measured depth, which is along its axis and near the north end, is more than 1,685 feet (513 meters). Obscure gravel terraces indicate that for a short time in the Pleistocene period the lake was at least 80 feet (24 meters) higher than at present. Its level (altitude 6,225 feet, or 1,897 meters) is now controlled by a low dam at the outlet, which forms the Truckee River. To the west is the front of the Sierra Nevada, here scarcely 10,000 feet (3,048 meters) in altitude but strongly carved by ancient glaciers of which no remnants have survived. The origin of the lake basin is unknown, but warping and faulting seem the most probable agencies in its formation. Neither glaciation nor volcanic dams appear to be involved.

201.7 (324.6). At this point the road reaches the shore of the lake. A wave-cut bluff 25 feet (7.6 meters) high reveals river sand in which a few small boulders are scattered. This material forms the old delta plain of the upper Truckee River, probably constructed during the Tahoe glacial stage.

208.3 (335.2). Outlet of Fallen Leaf Lake. Around the south end of Lake Tahoe the route crosses the terraced delta plain. Here along the base of the Sierra Nevada the road touches the first of a series of glacial moraines of the Tahoe and Tioga stages. Mount Tallac, to the southwest, consists largely of metadiabase and hornfels, with granodiorite intruded into it on the north.

210.7 (339.1). [10] From this point, on the bulky moraine (Tahoe stage) of Cascade Lake, there is a fine view of the southern shore of Lake Tahoe (pl. 15) with the Carson Range in the distance. The effects of ancient forest fires in rending the glacial boulders are visible at many points along the road in the next mile or two.

211.1 (339.8). Cascade Creek. The road here curves around the sloping front of a terminal moraine of Tioga age. The extreme abundance of undecayed boulders is typical of these youngest moraines.

212 (341.2). [11] Emerald Bay is really a glacial lake inclosed by moraines of the last or Tioga stage. The tiny delta at its head is typical, although it is now modified to serve as a boat harbor. From this point on the joint lateral moraine one can also look down upon Cascade Lake to the south. All the rocks along here are granitic.

214.3 (344.9). On the northwest side of Emerald Bay, after passing granite roches moutonnées, is the best section of a young glacial moraine (Tioga stage) to be seen on this route. The gray color, the undecayed and, in places, striated condition of the boulders, and the absence of a top soil are typical of that stage.

215.7 (347.1). Road cuts on this unglaciated hill show the granite disintegrated and stained to depths of 25 feet (7.6 meters) or more. Exfoliation probably due to hydration has produced many large pseudoglacial boulders.

217.9 (350.6). At the edge of the plain, but little above lake level, cuts reveal evenly laminated and ripple-marked sand, silt, and fine gravel that were probably deposited in Lake Tahoe late in Pleistocene time.

219.4 (353). Road cuts here expose complexly stratified gravel 200 feet (61 meters) above Lake Tahoe. They appear to be glacial outwash deposits of the Tahoe stage, now greatly eroded by stream action.

221.3 (356.2). [12] Meeks Bay (south side). Bulky lateral moraines of the Tahoe stage inclosing smaller ones of the Tioga stage enter the lake on both sides of the bay. The decay of boulders in the Tahoe till is easily seen in the road cuts. The mountains on the left still consist largely of granodiorite.

225.3 (362.6). [13] McKinney Creek. Here another glacier entered the lake and left the usual moraines. For 10 miles (16 kilometers) north of this point the range is carved from the andesitic series, which overlies the granodiorite. Several of the highest peaks are in fact denuded necks of the old andesite volcanoes.

228 (366.9). Just north of Blackwood Creek a vertical wave-cut cliff of early Pleistocene (?) basalt faces the lake. This basalt, probably faulted down on the left, is the first appearance of a formation that becomes more prominent near Truckee. From this point northward the road crosses forested alluvial fans and follows in part a Recent beach of Lake Tahoe, some 12 feet (3.6 meters) above the present lake. Obscure traces of more ancient shores at higher levels are concealed by the forest.

232.5 (374.2). Tahoe Tavern stands on a wave-built gravel terrace about 35 feet above the lake. Just north of it there is a broad trench through which the lake overflows, forming the Truckee River. The river has cut a narrow valley through the andesitic and basaltic volcanic rocks that fill the depression between the Sierra Nevada and the granitic Carson Range. Little is yet known of the geomorphic

history of this locality. Although block faulting or warping is commonly supposed to be the cause of the Tahoe Basin, the evidence is obscure or lacking.

237.3 (381.9). On the left the valley of Bear Creek was occupied by a glacier which left a frontal moraine of the Tioga stage, flanked by two much higher lateral moraines of the Tahoe stage.

239.3 (385.1). [14] Squaw Creek. This tributary canyon from the left also afforded a channel by which glaciers of the Tahoe and Tioga stages descended to the Truckee River. The glacier obstructed the river and forced it to cut its east bank heavily. The Tioga stage frontal moraine is a low but very bouldery ridge skirting the road south of this point, while the truncated lateral moraines rise 200 feet (61 meters) on each side.

247.2 (397.8). Southern Pacific Railroad (main line). For the last 1½ miles (2.4 kilometers) the left bank consists of decayed till of the Tahoe stage, forming lateral moraines of the two glaciers that descended from the crest of the Sierra Nevada toward Truckee. On the right columnar basalt, which may be of early Pleistocene age, forms palisades. Another high lateral moraine rises on the north side of the valley ahead. Granite has again become the prevailing rock of the Sierra Nevada crest.

248.8 (400.4). Truckee (altitude 5,818 feet, or 1,773 meters). This lumber and railroad town is surrounded by maturely eroded hills of andesite and basalt, now partly concealed by old glacial deposits and terrace gravel of the Sherwin and Tahoe stages. Terraces 25, 60, and 180 feet (7.6, 18, and 55 meters) above the river are correlated with the last three glacial stages in the mountains. Their well-stratified deposits of gravel, sand, and boulders are clearly exposed in new road cuts east of the town.

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Pyramid Peak, California.
Truckee, California.

RENO AND VICINITY

By J C. Jones and Vincent P. Gianella

INTRODUCTION

The area in the vicinity of Reno, Nevada, presents two geologic problems that have been much discussed by scientists and with wide variation in opinion—Quaternary climates, as illustrated by the fluctuation of the lakes; and the origin of the Basin Ranges.

As the region is in the western part of the semiarid Great Basin, slight changes in the annual rainfall produce significant changes in the relative amount of precipitation and cause large fluctuations in the depth and areal extent of the lakes. The beaches and sediments of Lake Lahontan indicate at least three great expansions of the lakes, which seem to be relatively recent if the slight amount of erosion and freshness of the lacustrine sediments are considered. Earlier studies by King (56) [10] and Russell (64) correlated the fluctuations of Lake Lahontan with the Pleistocene glaciation, an interpretation strengthened by the presence of certain members of the Pleistocene mammalian fauna in the lake beds. In recent years Antevs (49) and Huntington (52) have followed this interpretation. Jones (54, 55), on the other hand, has been led to the conclusion that the three stages of Lahontan are but the last manifestation of some forty fluctuations of the lakes during Pleistocene time and that the Lahontan stages occurred during the present era, with the survival of the fauna till the last thousand years. The recent discovery of the association of artifacts and the fauna in the southern part of the State offers additional evidence indicating the recent existence of the fauna.

The origin of the Basin Ranges has been an open problem ever since they were first described. Although most of the geologists familiar with the area recognize that block faulting has played the major part in their formation, yet others hold that they have been formed largely through the agency of erosion. In this area the movements are still active, and the recent fault scarps are clearly evident along the fronts of the ranges. In 1915 the Sonoma Range, 125 miles (201 kilometers) east of Reno, moved along a normal fault, forming a scarp similar to those seen in the Reno area. Many of the Basin Ranges are not simple tilted blocks but are a mosaic of several blocks, each with its individual tilt, and transverse faulting is not uncommon. Most of the faults are apparently normal, yet there is a suggestion

[10] Numbers in parentheses refer to bibliography, pp. 101–102.

that some are in reality thrust faults with a high angle. The final solution of the problem awaits a comprehensive detailed study of the individual ranges.

Reno is near the western border of the Great Basin, with the Sierra Nevada to the west. The climate is semiarid, and the vegetation consists of the characteristic sagebrush, juniper trees, bunch grass, and occasional cacti of the desert. The annual rainfall ranges from 7 inches (17 centimeters) at Reno to 3 inches (7 centimeters) at Pyramid Lake. The bulk of the precipitation falls during the winter. Agriculture depends entirely on irrigation and is limited to about 3 per cent of the area of the State, because of the small amount of water available. The mountains are used for pasturage of sheep and cattle, and at higher altitudes there are scanty pine forests.

The native animals are jack rabbits, coyotes, ground squirrels, sage hens, badgers, lizards, and snakes, with occasional antelope, deer, wild horses, and mountain lions in the mountains.

HISTORY

The first scientific exploring expedition in this area was that of Frémont in 1842. For a few years before the fur hunters had penetrated into the area along the Humboldt River and until the discovery of the Comstock lode in 1859, Nevada was a part of Utah Territory, and the deserts were one of the perils to be surmounted in crossing to the gold fields of California. With the development of the mines Nevada was organized as a separate State and admitted to the Union in 1864.

The population has fluctuated until recent years, with the progress of the mines, and in 1930 was 91,058, of whom 18,529 were in Reno and the bulk of the remainder in the other cities and towns along the railroads. The production of the State is chiefly agricultural and mineral, though a small amount of manufacturing is done, which will probably increase with the completion of the Hoover Dam, near Las Vegas.

Reno (altitude 4,500 feet, or 1,372 meters) is situated in an intermontane valley, bordered by the Sierra Nevada (9,000 to 10,000 feet, or 2,743 to 3,048 meters) on the west and the Virginia Range (6,000 to 7,000 feet, or 1,829 to 2,134 meters), the westernmost of the Basin Ranges, on the east. It is the financial center of the State and the seat of the State University and the Mackay School of Mines.

GEOLOGY

Older sediments and extrusive rocks.—The oldest rocks of the Reno region consist of a series of interbedded lavas and sediments

metamorphosed in varying degrees by deformation and the action of intrusive granitoid rocks. They include black shaly limestones and carbonaceous shales, volcanic tuffs, breccias, and lavas, with a few thin beds of conglomerate and impure sandstone. In places the finer-grained rocks have been metamorphosed to slates and andalusite-biotite schists. The volcanic rocks are in general much chloritized and contain epidote and some tourmaline. In some areas these older rocks have been changed into masses of nearly pure epidote by igneous metamorphism. Their age has not been determined, as the few fossils found are poorly preserved; they are probably Triassic, though in part they may belong in the upper Paleozoic.

In Eldorado Canyon, about 10 miles south of Virginia City, similar metamorphosed rocks are apparently overlain by a series of shales and limestones that contain marine fossils of Upper Triassic and Lower Jurassic age. These less metamorphosed sediments contain lenses of graphite derived from coal, indicating occasional deltaic or terrestrial conditions.

In addition there are small areas of tuffs and lavas that are older than the granitoid rocks but are thought to be somewhat younger than the older series because of their lesser degree of metamorphism.

Intrusive rocks.—Intruded into the sediments and lavas is a series of granitoid rocks ranging from granite through quartz monzonite and granodiorite, to diorite, collectively called the Granite series. Owing to the nature of the intruded rocks contact metamorphism is confined mostly to the immediate contact with the granite. Epidote is the most common mineral formed, though some tourmaline, garnet, and iron sulphides occur. At the contact both the granite and the schists are cut by aplite dikes, and rarely pegmatites with large crystals of quartz, orthoclase, microcline, and albite, as well as beryl and tantalates, are found.

The gold veins of Peavine Mountain, the arsenic, lead, and zinc deposits of the Galena Creek and Wedekind districts, and the copper deposits north of Reno were formed at the time of the intrusion of the granite.

Late Tertiary lavas.—The early part of the Tertiary was evidently a period of erosion in this region. Lying unconformably on the "Bedrock complex" is a series of lavas interbedded with lake beds of late Miocene or early Pliocene age. The lavas range from rhyolite to augite andesite and basalt and include tuffs and breccias. At the base is rhyolite, but the most widespread member is the succeeding andesitic breccia, which in places rests directly on the granite and schists. Overlying the breccia and grading through tuffs are the Truckee lake beds

(early Pliocene), including tuffaceous sand, clay, diatomaceous earth, and impure lignite. The lake beds are overlain by a thick series of basalts. Interbedded with the earlier lavas are river-channel deposits that in places contain auriferous gravel.

The principal mineralization of the Comstock lode occurred soon after the extrusion of the Tertiary lavas. During the remainder of the Pliocene the lavas and lake beds were faulted, tilted, folded, and beveled by erosion. Basalt and Quaternary gravel rest unconformably on this erosion surface.

Quaternary faulting.—Toward the end of the Tertiary the region had been reduced to an area of low relief. In late Tertiary or early Pleistocene time the basin area was broken into a series of blocks bounded on one or more sides by faults. The faults strike in three general directions—nearly due north, N. 30° E., and N. 30° W. The trend of any particular basin range depends upon which particular system of faults dominates the structure. Some of the ranges are compound, with faults of two or more strikes intersecting within them. The Virginia Range is made up of blocks bounded by both northerly and northeasterly faults. On the other hand, the range just west of Spanish Springs Valley is a simple block bounded on the east by a northeasterly fault.

The displacement of the blocks can be estimated by the different altitudes of the late Tertiary erosion surface, lavas, and river channels found preserved in mountains and foothills alike where not buried by the Quaternary sediments. In this area the displacement ranges from a few hundred feet to 4,500 feet (1,372 meters) along the east front of Mount Rose. The elevation of the mountains is largely due to the tilting and rotation of the crustal blocks rather than to simple elevation. In 1915 the Sonoma Range, about 100 miles (161 kilometers) northeast of this area, was elevated from 5 to 15 feet (1.5 to 4.5 meters) by a fault that extends 23 miles (37 kilometers) along the western base of the range (53). Recent fault scarps are common along most of the ranges in the vicinity of Reno, and although none of them have shown visible movement during the last seventy years, yet they are still relatively fresh and resemble the recent scarp along the Sonoma Range.

Glaciation.—During the Pleistocene epoch the upper parts of the valleys and depressions in the higher Sierra were occupied by small valley and cliff glaciers. There is evidence of slight glaciation in the Virginia Range. The glaciers deepened the canyons and formed small cirques, but the modification was slight compared with that effected in the High Sierra. With the exception of the Ophir Creek glacier, south of Slide Mountain, no late moraines reached the eastern valleys, and the terminal

moraines are largely confined to the canyons. The moraines of this area are very fresh, and the glaciers were probably active relatively late in the Pleistocene. The recent age of the glaciation is further suggested by the fact that the glaciers occupied deep canyons that had been cut through the fault scarps. The fact that the moraines are but slightly faulted demonstrates that the greater part of the elevation of the mountains had already been accomplished before the last glacial epoch.

Pleistocene and Recent sedimentation.—The intermontane valleys are largely filled with the clay, sand, and gravel washed from the adjoining mountains, forming great alluvial fans and aprons with a few playas or mud flats. Several wells drilled in the vicinity of Reno have reached depths as great as 1,500 feet (457 meters) in alluvium without reaching the underlying Truckee lake beds. The deepest well yet bored in western Nevada was drilled in the Carson Sink near Fallon, about 60 miles (97 kilometers) east of Reno, and reached a depth of 3,000 feet (914 meters) in alluvium before passing into the underlying basalt.

Pleistocene and Recent lakes.—As the precipitation in the Great Basin is slight, averaging less than 10 inches (25 centimeters) annually, a small increase or deficiency in the precipitation causes a wide variation in the relative amount. As a result, the lakes of the region have been a very sensitive indicator of variations in precipitation. For example, Pyramid Lake rose 18 feet (5.4 meters) in 1890, owing to an increase of about 5 inches (13 centimeters) above the normal precipitation.

Lakes of the past have occupied the valleys over wide areas. The largest one in western Nevada was Lake Lahontan, whose surface had an area of 8,000 square miles (20,720 square kilometers) and whose maximum depth was nearly 900 feet (274 meters). At present only Pyramid, Winnemucca, and Walker Lakes are left as remnants, and the remainders of their basins are dry playas, or ephemeral lakes like the Carson Sink.

The sediments of Lake Lahontan can be seen resting on the preexisting alluvial fans, and in the vicinity of Pyramid Lake three stages of expansion are clearly shown. These have been correlated with stages of continental glaciation, especially as the fauna found in the lake sediments contained the elephants, horses, camels, and big cats of the so-called Pleistocene fauna (49, 52, 64). In wells drilled in the Carson Sink, however, it has been found that Lake Lahontan represents only the last three stages of about 40 Pleistocene lakes, some of which had a much longer period of existence than Lake Lahontan (55). Further work has shown that the present lakes are remnants of Lake

Lahontan and that the present rate of accumulation of the salts can be safely used to determine its age (54).

On the basis of his studies along these lines the senior author has come to the conclusion that Pyramid and Winnemucca Lakes began their existence with the first expansion of Lake Lahontan, about 2,000 years ago, and that Walker Lake first became a part of Lake Lahontan during the second stage, about 1000 A. D. These two determinations agree with the dates of increased precipitation indicated by the wider annual rings of the sequoias of the Sierra Nevada and would indicate that the third and last stage probably centered about 1350 A. D. In this region, then, the large animals of the late Pleistocene fauna must have survived until well into historic time.

PETROGLYPHS

The original inhabitants of the region left signs engraved on the rocks near their camp sites. These are difficult to interpret but appear to be maps, pictures of the common animals of the area, and occasional word signs that are believed by some students to resemble ancient Chinese.

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ITINERARY, RENO TO PYRAMID LAKE AND RETURN

[See pl. 16]

By J C. Jones

Leaving Reno, the excursion will follow down the Truckee Canyon through the Virginia Range to a point near Hazen, return to Wadsworth by way of Fernley, and then follow the Truckee River to Pyramid Lake, follow the west shore of the lake for 15 miles (24 kilometers), and return to Reno through the

Virginia Range and along other Basin Ranges. The points of interest along the route are indicated on the route map by numbers. The purpose of the trip is to view the evidence of displacement and recent movement of the Basin Ranges and to gain a first-hand acquaintance with the evidence for the recent climatic changes in the Great Basin, including the history of Lake Lahontan.

At the start the route passes east across the Truckee Meadows, the valley lying between the Sierra Nevada to the west and the Virginia Range to the east. The valley has been tilted to the east, as is indicated by the eastward tilt of the Truckee lake beds and river terraces and the shifting of the lateral streams to the extreme eastern border of the valley. The low ridge to the north is a remnant of the old erosion surface that caps all the hills and mountains in this area. This surface was formed after the deposition and tilting of the Truckee lake beds, which were laid down during early Pliocene time. The faulting that gave the present topography has chiefly occurred during late Pliocene and early Pleistocene time and is still continuing.

About 3 miles (4.8 kilometers) east of Reno is the city of Sparks, a division point on the Southern Pacific Railroad. North of Sparks the prospect holes and mines of the Wedekind mining district may be seen. This district has produced about $250,000 worth of lead-silver ore. The mineralization occurred at the time of the intrusion of the granite (late Mesozoic).

[1] [11] From a point about 2 miles (3.2 kilometers) east of Sparks the terraces along the front of the Virginia Range can be viewed. These mark the position of the branching fault along which the range was elevated and tilted to the east. To the west similar terraces can be observed along the east front of the Sierra Nevada. The marshy ground at the foot of the Virginia Range is in part caused by the eastward tilt of the valley and in part by the delay in the river in cutting down the rock brought athwart its course by the elevation of the mountain range. The river is antecedent to the range, as a low pass to the north would have given an outflow from the valley if the range preceded the river. The mountains rose gradually, and the river has been able to cut its channel rapidly enough to avoid diversion.

[2] (9 miles, or 14.5 kilometers [12]). Metamorphosed lavas of Mesozoic age occur in the bottom of the canyon, and on the dark rocks are a number of petroglyphs, one telling the story of a hunt along the river. One of the larger problems of the area is to distinguish the older pregranitic lavas from those of Ter-

[11] Numbers in brackets refer to route map, Plate 16.

[12] Distance from Reno.

tiary age. This is readily done where, as here, the old lavas have suffered contact metamorphism, but away from the granitic contacts where both lava series are fresh it is difficult.

Beyond this point the road follows along the Tertiary flows, and occasionally the interbedded Truckee lake beds can be seen. The loose, poorly assorted gravel deposits seen in the road cuts are talus slopes and small alluvial fans, which in a general way resemble glacial till.

About 2 miles (3.2 kilometers) farther on the road passes over and near some recent basalt flows that came from dikes a short distance north of the highway. These flows reached the river in places and forced it to flow along the south wall of the canyon.

[3] (15 miles, or 24 kilometers). At the summit of a hill there is an opportunity to examine the Tertiary basalts that here form the bulk of the range and to view the canyon. The old erosion surface can be seen tilted to the east in the western part of the range and to the west in the eastern half of the range. The Virginia Range is a compound range formed by faults striking due north, N. 30° E., and N. 30° W. As a result it is formed of several crustal blocks, each with its individual tilt. At the foot of the hill the western limit of Lake Lahontan is encountered and the small sand dunes that have been blown from the beach sands. Along the slope of the small hill beside the road about 2 miles (3.2 kilometers) farther east the faint beaches of the old lake are preserved.

[4] (20 miles, or 32 kilometers). Here there is a good section of the Lake Lahontan sediments lying on and interbedded with the alluvium washed from the walls of the canyon. Portions of the lake beds are contorted as a result of slumping into the canyon as they were deposited. The lake sediments were laid down as isolated patches in quiet water along the walls of the canyon, instead of completely filling the canyon, as might be expected.

About 3 miles (4.8 kilometers) farther on the road runs between a high, steep cliff of the later Tertiary basalts and a bend of the river. A short distance beyond this point the Derby Dam is reached. This dam diverts the water of the river into the canal that leads along the south bank of the river to the Lahontan Reservoir, on the Carson River. The dam and canal are a part of the Newlands project, the first of the great irrigation works accomplished by the United States Bureau of Reclamation, and furnish the water for the irrigation of the lands near Fernley and Fallon.

For the next 4 miles (6.4 kilometers) the lava beds dip to the southwest, as is shown by a prominent bed of volcanic ash south of the river. In the saddle of the ravine to the east of the ash

is seen the yellowish diatomaceous earth of the Truckee lake beds, near the top of the range.

[5] (28 miles, or 45 kilometers). At Derby the road leaves the canyon and follows the old grade of the Central Pacific Railway. A short distance beyond a stop will be made to view the late Tertiary rhyolite and tuffs that underlie the basalts, also the Lake Lahontan silts in patches as originally deposited in the quiet places along the valley walls.

About 5 miles (8 kilometers) farther on the road passes through Wadsworth. Here the Truckee River turns north to Pyramid Lake, and the road crosses the river and continues through a sandy area to Fernley. Fernley is the center of an area irrigated from the canal leading to the Lahontan Reservoir and reclaimed from the desert during the last 20 years.

The sands are Lake Lahontan sediments that have been modified by the action of the wind. On both sides of the valley the beach marks of the old lake can be plainly seen, and the valley leading northeast from Fernley is a typical playa and a desiccated part of the Lahontan Basin. The pre-Lahontan channel of the Truckee River is faintly marked as a channel leading east from Fernley to the playa. After flowing into the fresh-water lake that occupied the playa at that time the river flowed out near its entrance through a channel that passes near Hazen. (See pl. 14, *B*.)

[6] (46 miles, or 74 kilometers). The old channel of the Truckee is eroded to a depth of 30 to 40 feet (9 to 12 meters) through a ridge of Tertiary lake beds. To the north the hills have a thin coating of eolian sands blown from the playa by the winds. These scanty sands are the only visible evidence of eolian erosion.

Returning through Fernley to Wadsworth the route leaves the main highway and follows a typical desert road to the Truckee Narrows. Several small playas are visible, and the general aspect of the semiarid landscape is typical of a large part of the State of Nevada. The steep slope of the mountain range to the east is a fault scarp, and the flat-topped ridges are tilted to the east. Along the front the beaches of Lake Lahontan are clearly shown. The light-colored area to the west is the Olinghouse mining district.

[7] (10 miles, or 16 kilometers [13]). At the narrows of the Truckee River the canyon is cut through the lake sediments into the pre-Lahontan alluvium and basalt. When, according to the writer's interpretation, Lake Lahontan rose for the first time, about the time of Christ, it overflowed its basin at the narrows

[13] Distance from Wadsworth.

and occupied the valleys of Pyramid and Winnemucca Lakes, cutting a channel through the alluvial dam that had formed the divide. This reversed the drainage of the ravines in the range to the east, and they now have a general southerly course, with a sharp turn to the north as they enter the river. With the recession of the lake the river followed the new channel and abandoned the old outlet to the Carson Sink.

Since Lake Lahontan time the river has cleared out most of the lake sediments, and on the walls of the canyon the lake silts can be seen resting upon the pre-Lahontan alluvium. From the narrows the route leads across the valley to the south end of Pyramid Lake.

[8] (20 miles, or 32 kilometers). Beside a well-developed tufa dome an opportunity will be given to examine the tufa. The tufa was classified by Russell (64) in three varieties—lithoid,

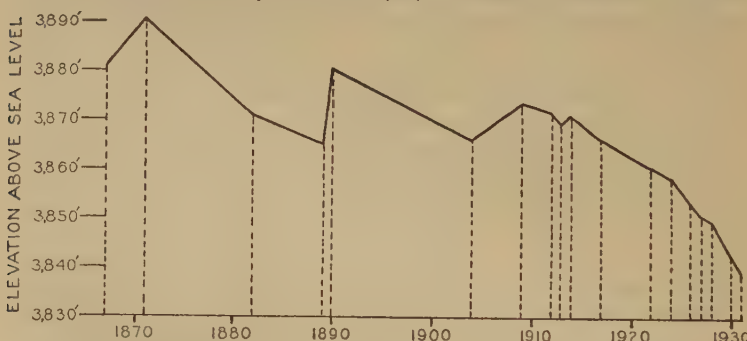
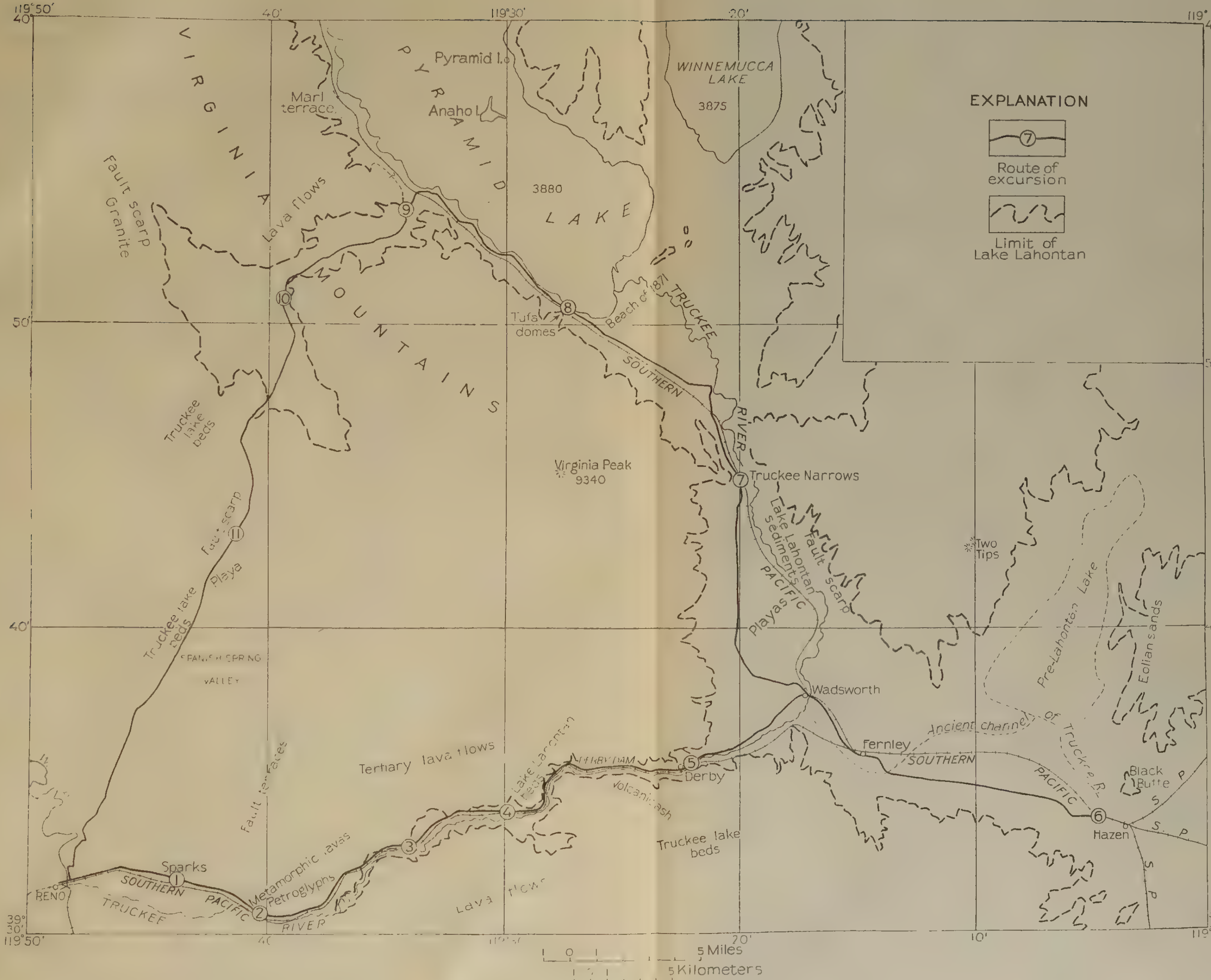


FIGURE 16.—Known altitudes of water surface of Pyramid Lake

stony and compact; dendritic, coralline and branching; and thinolite, showing crystal forms. Both the lithoid and dendritic varieties are now known to have been deposited through the activities of blue-green algae and are forming along the lake shores at the present time. The thinolite, however, is a paramorph of calcite after aragonite and may have been deposited at a time when the waters of Lake Lahontan were oversaturated with calcium carbonate. The tufa formed only on a solid foundation, such as rock or gravel, that furnished a support for the algae, but once started it formed around any sand or pebbles that happened to fall among the plants.

The delta of the Truckee River can be seen, and bordering the south end of the lake is a barrier beach that was formed in 1871. The lake has since fallen by intermittent stages more than 50 feet (15 meters). Figure 16 gives the determined altitudes of the lake during the last 60 years.



ROUTE MAP, RENO TO PYRAMID LAKE

Numbers in circles indicate localities mentioned in the text.

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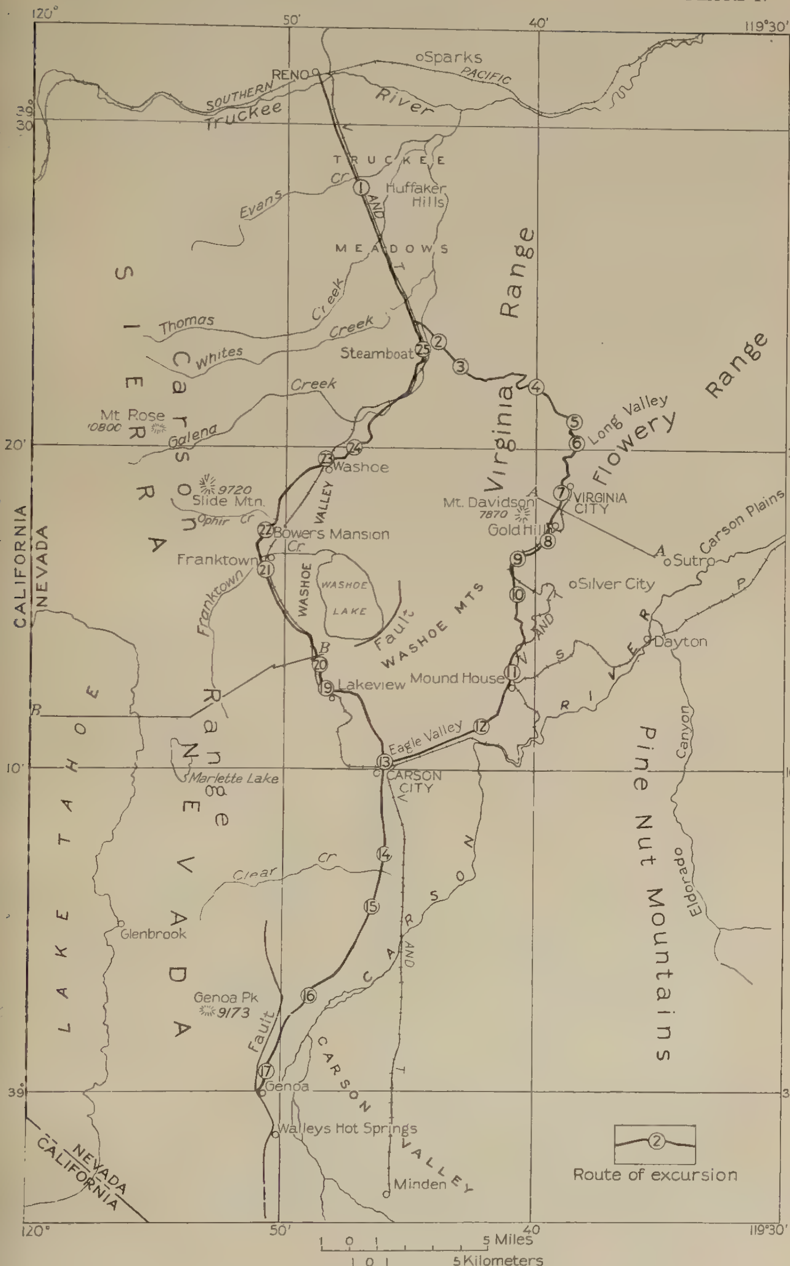

ROUTE MAP, RENO TO GENOA

Numbers in circles indicate localities mentioned in the text.

A. VIRGINIA CITY, NEVADA

Mount Davison on the right. The outcrop of the Comstock lode follows approximately the base of the mountain. Photograph by Curtis.

B. RECENT FAULT SCARP AT GENOA, NEVADA

The scarp is indicated by the light band along the base of the range. Photograph by Curtis.

For the next 10 miles (16 kilometers) the road leads along the shore of the lake. A gravel pit about 3 miles (4.8 kilometers) north of the last stop gives a good idea of the structure of the lake bars. The large island toward the eastern shore, Anaho Island, stands 550 feet (168 meters) above the lake and was submerged 10 feet (3 meters) when Lake Lahontan was at its highest. Pyramid Island is farther north and suggested the name of the lake to Frémont when he first saw it in 1841. The deepest part of the lake lies just north of Pyramid Island and is about 325 feet (99 meters) deep. The lake is from 7 to 12 miles (11 to 19 kilometers) broad and 28 miles (45 kilometers) long. The water is brackish, containing about 3,500 parts per million of dissolved salts. Three unique species of fish occur in Pyramid Lake, and their remains are also found in the Lake Lahontan sediments (65).

[9] (30 miles, or 48 kilometers). As the route leaves the lake a stop is made at the summit of the hill at Mullins Gap, and a last view of the lake and the Lahontan terraces is to be had. The well-marked terrace about 150 feet (46 meters) above the lake is the thinolite terrace of Russell (64) and is the only terrace cut in rock, as on Anaho Island, in the Lahontan basin. The fluctuation of the water surface of the lake was usually too rapid to accomplish more than the notching of preexisting alluvium. The terraces to the south show how little erosion has accomplished since the retreat of the waters of the great lake, as the talus slopes above the beaches have advanced but slightly over the beach lines.

For the next 7 miles (11 kilometers) the road follows a valley across the Virginia Range. The range is more simple here, with a fault on the western face and a tilt to the east. It is a volcanic complex, and a volcanic neck can be seen on the sky line to the north.

[10] (37 miles, or 60 kilometers). From the summit of a low saddle the Tertiary volcanic rocks of the Virginia Range and the granites of the next range to the west can be seen. The fault scarp along which the lavas have been downfaulted can be seen along the base of the granite range. For the next 10 miles (16 kilometers) the road crosses an intermontane valley and through a small transverse pass into the next depression to the west, known as Spanish Spring Valley.

[11] (48 miles, or 77 kilometers). The southern part of the range that bounds the west side of Spanish Spring Valley is composed of granite intruded into Mesozoic schists to the north, both capped by the late Tertiary rhyolite. About the center of the range a small shoulder of the rhyolite is displaced halfway down the slope by a branch of the fault along the base. At the

foot of the mountain are the Truckee lake beds. A small playa occupies a sag hollow at the north end of the larger valley.

From this point the road leads to Reno along the west slope of Spanish Spring Valley and on the summits of the passes crosses over the old erosion surface. The low rolling topography beyond the first summit is characteristic of the old surface as found on the tops of the mountain ranges. The rocks are old lavas and granites of Mesozoic age, with rare residual patches of the Tertiary lavas capping the projecting hills.

ITINERARY, RENO TO WALLEY HOT SPRINGS AND RETURN

[See pl. 17]

By Vincent P. Gianella

Proceeding south on the Reno-Carson Highway, through the Truckee Meadows, the route affords an excellent view of the Carson Range, which forms the eastern front of the Sierra Nevada, and of the Virginia Range to the east, which is the westernmost of the numerous Basin Ranges. Fault scarps bound the Carson Range on its eastern base and also the western base of the Virginia Range. The intervening Truckee Meadows lie upon the dropped block between them. In several places recent scarps are to be seen along the foot of the mountains. The floor of the valley is shown by borings to be underlain by sand, clay, and gravel several hundred feet in thickness. The Truckee lake beds crop out along the flank of the Sierra Nevada and dip east under the alluvium.

5 (8).[14] [1] [15] To the east of the highway are the Huffaker Hills, surrounded by alluvium. They constitute a portion of the Virginia Range that has been faulted down to a lower level. An old erosion surface is seen on the hills and on the mountains just beyond. On the flank of the range fault terraces are plainly visible. Steamboat Creek flows between the largest hill and the Virginia Range.

11 (18). [2] About half a mile to the west are the Steamboat Springs, issuing from crevices in the white, siliceous sinter terrace built up from mineral matter contained in the waters. Beyond the springs are seen faceted spurs at the base of the Sierra Nevada.

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[14] Figures indicate distance from Reno in miles, with kilometers in parentheses.

[15] Numbers in brackets refer to route map, Plate 17.

12½ (20). [3] Here the road leads up the steep Geiger grade over the western escarpment of the Virginia Range.

15 (24). [4] The road passes over a mature erosional surface on the crest of the range, forming the divide between the drainage to Steamboat Valley and that leading northward to the Truckee Canyon. Youthful valleys are rapidly cutting back into the old surface. From this point there is a good view of the eastern escarpment of the Sierra Nevada, culminating in Mount Rose (altitude 10,800 feet, or 3,292 meters), the highest peak in this part of the range. Dark Tertiary volcanic rock forms the top of the mountain and overlies the light-colored diorite, and a down-faulted lava-capped shoulder is seen on the eastern slope of the mountain.

18 (29). [5] To the northeast, over a mature erosion surface, the white Truckee formation, containing much diatomite, is seen in the distance at the foot of the Flowery Range, which is made up of late Tertiary hornblende andesite.

19½ (31). [6] The route here crosses a divide between the drainage of the Truckee and Carson Rivers and then follows along the side of the mountain on the footwall of the fault zone in which the Comstock ores were deposited. To the right are bold outcrops of dikes of Tertiary lavas which cut through the older lavas.

22 (35). [7] Virginia City (pl. 18, *A*). To the west is Mount Davidson, 7,870 feet (2,399 meters) above sea level, a monadnock rising somewhat above an old erosion surface that extends westward. Virginia City stands in part on remnants of this surface, which has been faulted to its present altitude of 6,200 feet (1,890 meters), representing a minimum displacement of about 1,500 feet (457 meters). Other portions of the surface are seen to the northeast. The average dip of the fault is 43° E., and the trace on the surface is indicated by outcrops of veins trending parallel to the mountain front. Just above these outcrops is a fresh scarp formed by the subsidence of the mine workings. The bulk of the mountain consists of old lavas intruded by hornblende diorite, and the hanging wall is made up of these older lavas, which are overlain by Tertiary lavas and breccias, as shown in Figure 17. To the east is seen a rugged range of Tertiary andesite hills, and beyond is the Carson River with the Pine Nut Range in the distance.

The Comstock lode was discovered in 1858 and has produced about $400,000,000 in gold and silver. The richest and most productive ore body, the Great Bonanza, was

found just east of the center of the town and extended from 300 to 1,900 feet (91 to 579 meters) below the surface. The production during recent years has been low.

24 (39). [8] The road descends a steep grade into Gold Hill, where another group of rich mines has been worked. Behind the town is a large open pit or glory hole, which was excavated when mines were operated in recent years. In the dumps, from mines which explored the footwall country rock, are seen dark slates, limestone, and lavas from the old metamorphic series of rocks.

26 (42). [9] To the west is the steep eastern escarpment of the Washoe Mountains, and to the east is American Flat, with late Pleistocene basalt flows along its eastern margin.

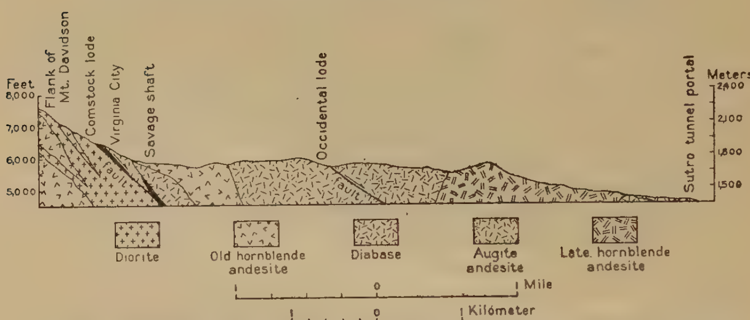

FIGURE 17.—Section from Mount Davidson to portal of Sutro tunnel. (See pl. 17.) Adapted from Geo. F. Becker and modified to show the intrusive nature of the Mount Davidson diorite.

27 (43). [10] Here near the old Florida mine is a good exposure of limestone and andalusite-biotite schist, which are part of the metamorphic series of rocks. The high dark hill immediately to the east is made up of Tertiary augite andesite. In the road cuts farther along are to be seen the older lavas and breccias, which are much metamorphosed and in places are almost completely epidotized. Some of the spurs to the west are capped by Tertiary rhyolitic lava.

30 (48). [11] Mound House. In the Washoe Mountains 1½ miles (2.4 kilometers) to the west are white dumps indicating the position of a large gypsum deposit. The gypsum occurs as a lens in limestone associated with metamorphosed andesitic lavas and breccias intruded by diorite and overlain by Tertiary rhyolite. Gypsum was formerly quarried and trammed to a mill about 1 mile (1.6 kilometers) north

of the town and converted into plaster. In this vicinity, along the edges of terraces, are light-colored gypsite deposits, formed through the solution, transportation, and redeposition of gypsum from the deposits in the mountains. To the southeast is the deep gorge of the Carson River, cut in the north end of the Pine Nut Mountains.

34 (55). [12] The road leads down into Eagle Valley, and Carson City lies directly ahead. To the south there is a good view of the Carson River as it emerges from behind Prison Hill and flows north in an open valley, then turning sharply to the east enters a deep gorge cut on the flank of the Pine Nut Mountains. Because of the resistant rocks in the gorge the stream has reached a temporary base-level and meanders over the valley floor.

38 (61). [13] Carson, the capital of the State of Nevada. In the early days it was the supply point for the mines and mills working the ores of the Comstock. At the State prison, 1½ miles (2.4 kilometers) to the east, at the base of Prison Hill, is a quarry for building stone. The stone is cemented alluvial-fan material, and in it are the well-preserved footprints of the sloth, elephant, horse, deer, and many other mammals and numerous tracks of birds.

3 (4.8).[16] [14] Proceeding south from Carson we pass opposite the low divide between the Eagle and Carson Valleys. A short distance to the west is the bold escarpment that marks the easternmost limits of the Sierra Nevada. Many recent small fault scarps are to be seen at the mouths of the ravines along the foot of the hills.

4½ (7). [15] The road cut exposes old alluvial-fan material which has been uplifted by recent faulting and, owing to diversion of the run-off from the mountains, has been subjected to lessened erosion. The drainage now skirts the sides of the old fan. Directly ahead is an exceptionally good example of a scarp, and the steep slope of the mountain disappears beneath the valley fill at the foot of Jobs Peak.

9 (14). [16] To the right is an embayment in the mountains as the fault turns toward the west, and directly ahead can be seen a fresh scarp cutting through the alluvium where it meets the slope of the range, as shown in Plate 18, *B*. For several miles south of this point the major faulting was confined to a narrow zone and developed a well-defined scarp along this part of the Sierra Nevada. It is but 6 miles (9.6 kilometers) from this point to Lake Tahoe on the west side of the Carson Range.

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[16] Distances from Carson for remainder of itinerary.

13 (21). [17] Genoa, one of the oldest settlements in the State and the first capital of the Territory. The old capitol is seen on the right shortly after entering the town. To the west, against the mountain, the recent fault scarp (pl. 18, *B*) is plainly visible. This scarp can be traced for several miles to the south and then is seen only every few miles, where it displaces the alluvium at the mouths of ravines. The Carson River here flows through poorly defined channels in a marshy region close to the foot of the mountains. Its old channel is along the main highway 4 miles (6.4 kilometers) to the east, near the central part of the valley. From this evidence the conclusion is reached that the river has been diverted from its former channel as a result of westward tilting of the valley block by recent faulting. Several miles to the south the main Sierra fault breaks into branches, and the eastern Sierra escarpment becomes less distinct.

15 (24). [18] Walley Hot Springs. The recent scarp is most distinct and shows its greatest displacement at the point where the river approaches the very foot of the range at Walley Hot Springs, where the bare rock of the footwall is exposed to a height of over 30 feet (9 meters). Here numerous hot springs issue from the fault.

The return to Carson is made by the same route. Leaving Carson the road runs northward through Eagle Valley and up the grade to Lakeview. To the west are well-defined fault terraces where the faulting has become distributive, giving a good illustration of step faulting.

4 (6). [19] After crossing over the summit at Lakeview, in a low divide, the Washoe Mountains are seen to the east, with a spur that connects with the Sierra Nevada extending to the west. To the north Washoe Valley is terminated by a similar connecting ridge. Immediately to the west the faulting in the Sierra Nevada is distributed to a considerable extent and the escarpment is not so conspicuous. The large landslide scar on Slide Mountain is plainly visible to the north.

6 (10). [20] To the left of the road at the foot of the grade are marshy depressions in the valley floor near the Sierra Nevada. These are probably due to renewed dropping of the valley block. Here the east end of section B (fig. 18) is crossed, and Lake Tahoe is but 6½ miles (10.4 kilometers) to the west, beyond the Carson Range. To the northeast is Washoe Lake, with the southeastern shore cutting into the foot of the mountains. Recent fault scarps extend along the foot of the Washoe Mountains and cause a dis-

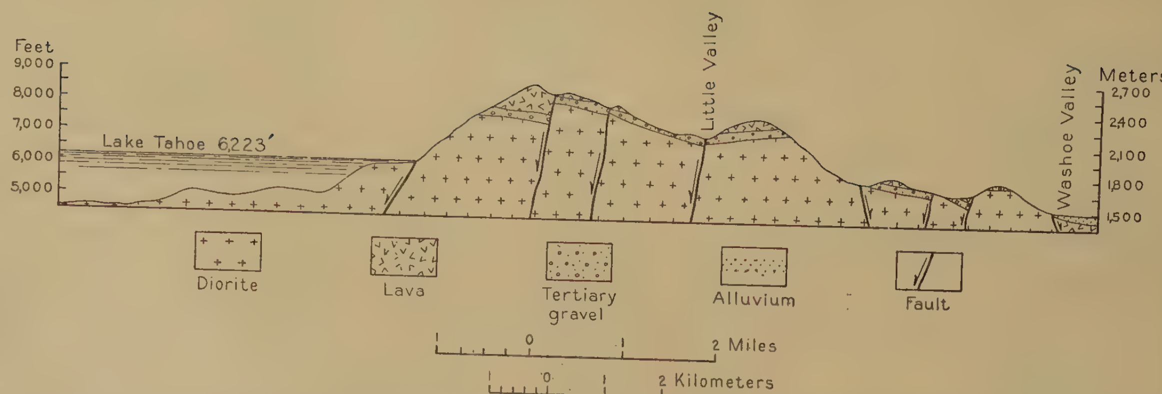

FIGURE 18.—Section from Lake Tahoe to Washoe Valley. (See pl. 17.) Here a Tertiary channel crops out of the scarp above Lake Tahoe and lies upon the surface of the diorite. It is capped by andesite and rhyolite and cut by many faults. The displacement on the Tahoe side is about 4,000 feet (1,219 meters) and toward Washoe Valley 3,400 feet (1,036 meters). The section is a modification of that by J. A. Reid (62)

placement of the lake by eastward tilting of the valley block. To the west the Sierra Nevada scarp is well defined for several miles to the north, as the faulting is again confined to a narrow zone.

9½ (15). [21] Franktown. Just beyond the town a small creek enters the valley through a sharp gorge in the face of the range. This stream drains a structural valley with a north-south trend, just behind the ridge to the west, and beyond is the main crest of the Carson Range. This valley is eroded along a fault that can be traced for several miles to the north. The valley has been dismembered north of Ophir Creek by eastward-flowing consequent streams which have cut gorges in the steep eastern slope of the range.

12 (19). [22] Bowers Mansion, built during the early days of the Comstock by one of the pioneers who made his fortune at the mines. Here the scarp on the face of the mountain meets the valley without the presence of an alluvial fan. The valley floor extends with a gentle slope directly against the mountains. From the base of the escarpment a stream of hot water issues from crevices in the exposed granitic rock. A short distance north of Bowers Mansion the road skirts the southern edge of a moraine and, turning to the north, crosses the east end of the glacial material. This moraine was deposited in the valley by a glacier coming down the Ophir Creek gorge south of Slide Mountain. It lies upon the valley floor at an altitude of 5,100 feet (1,554 meters), whereas the moraines at the mouths of White and Thomas Creek Canyons, a few miles to the north, are at 6,000 feet (1,829 meters) and that at Truckee is at 5,800 feet (1,768 meters). The Ophir Creek gorge is eroded along a transverse fault.

14 (23). [23] Washoe. About half a mile south of Washoe and also in the town itself Truckee lake beds are exposed in highway and railroad cuts. To the southwest these beds extend up the mountain slope and dip to the east. They are interbedded with tuff and gravel and grade into the underlying tuff without sharp demarcation. At the northern edge of Washoe Valley the railroad enters a sharp gorge cut through the late Tertiary lavas into the diorite. The waters draining from the Carson and Virginia Ranges into Washoe Valley pass through this gorge and finally reach the Truckee River below Sparks through Steamboat Creek.

15 (24). [24] The route follows the northern shore of Little Washoe Lake and climbs up to Washoe Summit over Tertiary breccia. Here again there is a low spur from the Virginia Range extending across almost to the Sierra

Nevada. To the west there is an excellent view of Mount Rose, rising steeply from the valley because of several parallel faults of large throw on its eastern flank. The very top of the mountain is capped with 200 feet (61 meters) of Tertiary andesite lying upon about 1,000 feet (305 meters) of volcanic breccia, which in turn rests upon the diorite. The breccia capping the mountain is the same as that on Washoe Summit, where it is well exposed in the highway

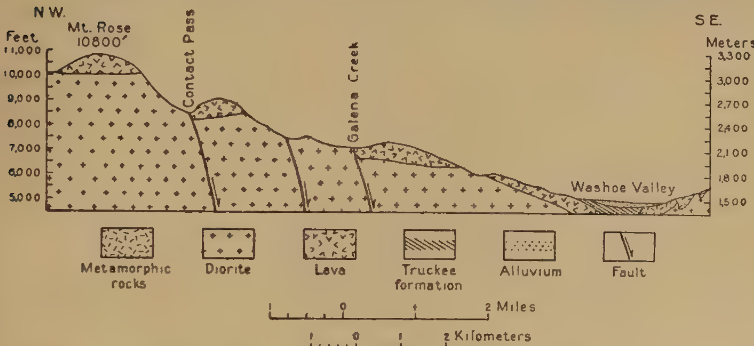

FIGURE 19.—Section from Mount Rose to Washoe Valley. (See pl. 17.) Showing three of the principal parallel faults along the east front of the Carson Range. At Washoe Valley the breccia, which is the same formation that caps Mount Rose, grades into the overlying Truckee formation. The displacement here is over 4,500 feet (1,372 meters)

cuts. From the top of the diorite, under the breccia on Mount Rose, to the top of the diorite underlying the breccia in the gorge below Washoe the difference in altitude is about 4,700 feet (1,433 meters), and this gives a rough measure of the total displacement along the front of the range at this point. Emerging from under the breccia within about half a mile of the highway and extending toward the east are the older rocks of the region. (See fig. 19.) They are intruded and metamorphosed by diorite, whose light-colored rugged outcrops occur to the southeast. To the northwest are the Steamboat Hills, composed of metamorphic rocks in places capped by Tertiary lavas.

20 (32). [25] Steamboat Springs. These springs are of great interest because of the spectacular issuance of steam and boiling water and also because they are actively depositing ore minerals at the present time. The muds contain small crystals of pyrite and stibnite and show on assay small quantities of gold and silver. Deposits of cinnabar due to these springs are found in the hills a short distance to the

west, where, for a short period, operations were carried on to obtain silica for use in glass manufacture. This silica is of remarkable purity (99.2 per cent SiO_2) and is composed of the residual quartz grains from granodiorite and of silica that was deposited by the hot waters while practically all the other constituents of the rock were removed. From Steamboat Springs the route retraces the road followed on the start of the trip.